IN-DEPTH SURVEY REPORT

CONTROL TECHNOLOGY FOR GALLIUM ARSENIDE PROCESSING

AT

M/A-COM
Lowell, Massachusetts

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I INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is the primary federal agency engaged in occupational safety and health research Located in the Department of Health and Human Services (formerly DHEW), it was established by the Occupational Safety and Health Act of 1970 This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control

Since 1976, ECTB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques Examples of these completed studies include the foundry industry, metal plating and spray painting operations, and HEPA-filtered vacuum enclosures used in the servicing of asbestos-type brakes The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures

These studies involve a number of steps or phases Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or techniques In-depth surveys are then conducted to determine both the control parameters and the effectiveness of these controls The reports from these in-depth surveys are used as a basis for preparing technical reports and journal articles on effective hazard control measures Ultimately, the information from these research activities contribute to the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury

This research study of control technology for gallium arsenide processing was prompted by a growing interest in silicon alternatives for the semiconductor industry For years, silicon had been the primary semiconductor material for integrated circuits However, demands for higher speed devices for communication and military purposes led to a surge in the development and use of gallium arsenide technology Gallium arsenide provides higher electron speeds, lower power consumption, and higher radiation resistivity than silicon Because of the increased demands for gallium arsenide, it will be useful to know if different or additional hazard controls are needed in comparison to silicon-based processes For instance, arsenic is considered to be a human carcinogen It is used as a raw material in the gallium arsenide production process and, therefore, gallium arsenide workers may be directly exposed to it Arsenic also may dissociate from inhaled gallium arsenide within the body

II PLANT AND PROCESS DESCRIPTION

FACILITY DESCRIPTION

M/A-COM produces gallium arsenide wafers, field-effect transistors, and monolithic microwave integrated circuits They grow gallium arsenide crystals by the Liquid Encapsulated Czochralski (LEC) technique The floor plans of the process areas evaluated in the NIOSH in-depth survey study are presented in Figures 1 and 2 M/A-COM constructed this building specifically for gallium arsenide production which began in 1984 At the time of the study, there were approximately 160 workers

PROCESS DESCRIPTION

Process Flow

For the LEC crystal growth process, the gallium and arsenic are loaded into a pyrolytic boron nitride crucible which is contained within a nitrogen-purged control box The crucible is carried to the crystal puller and placed in the crucible wall support The gallium and arsenic are melted at high temperature and high pressure in the presence of boron oxide The boron oxide floats on the melt and serves as a liquid encapsulant to prevent the arsenic from escaping The melt chamber is pressurized with argon A seed crystal is lowered into the melt in the crystal puller and the desired gallium arsenide crystal ingot is grown The LEC technique produces undoped, semi-insulating gallium arsenide ingots

The crystal orientation of the ingot is established and then one side of the ingot is ground flat on a surface grinding machine to mark this orientation The gallium arsenide wafers are slowly sliced from the ingot using automated saws The waste (consisting of butts, cones, and slurries) is recovered and sold to gallium producers for reclamation of the gallium Finally, the wafers are lapped to uniform thickness, polished, and cleaned Other processing steps include epitaxial growth, ion implantation, photolithography, etching, metallization, wafer thinning, wafer scribing, and packaging

In order to achieve the desired electrical properties, M/A-COM employs the vapor phase epitaxial process to grow thin layers of gallium arsenide on top of the wafers Arsenic trichloride, the arsenic source, is received in sealed glass ampoules packed in diatomaceous earth About once every two months, the arsenic trichloride is added to the epitaxial reactor which is enclosed entirely in an exhausted hood During operation, hydrogen and silane gas dopant are metered into the epitaxial reactor A portion of the hydrogen is directed over the arsenic trichloride liquid to entrain it into the reactor as a vapor in the hydrogen gas The reaction chamber is surrounded by a furnace which heats the arsenic trichloride, a polycrystalline gallium arsenide source, and the gallium arsenide wafers In the presence of hydrogen, the arsenic trichloride reacts with the polycrystalline gallium arsenide source to produce the volatile species of gallium chloride, arsenic (IV), hydrogen chloride, and smaller quantities of gallium trichloride and arsenic (II) The gallium chloride and the arsenic (IV) then react at the surface of the gallium arsenide wafer depositing gallium arsenide in a crystalline form The excess gases are

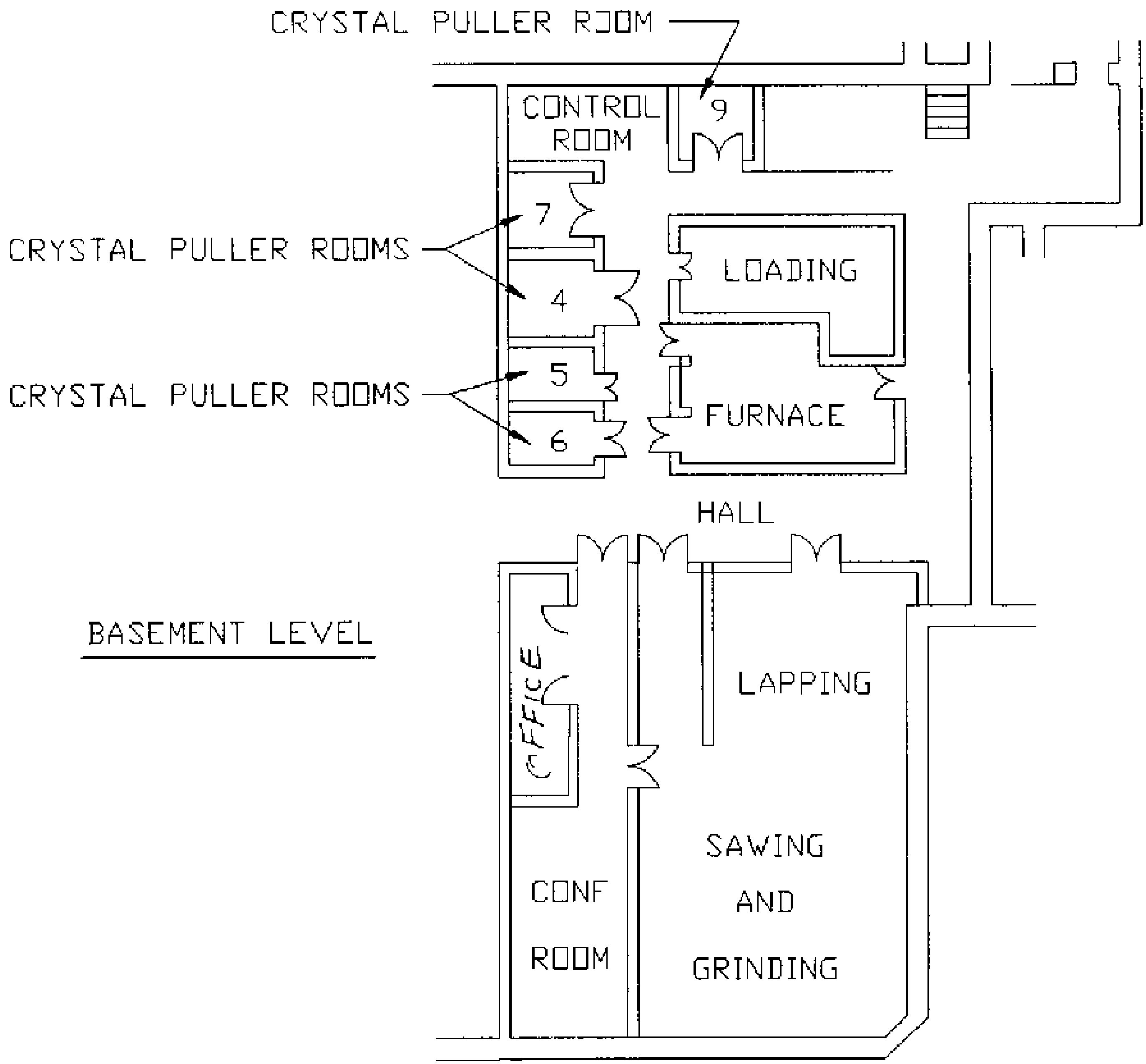


Figure 1. Plant Layout - LEC and Grinding/Sawing Areas.

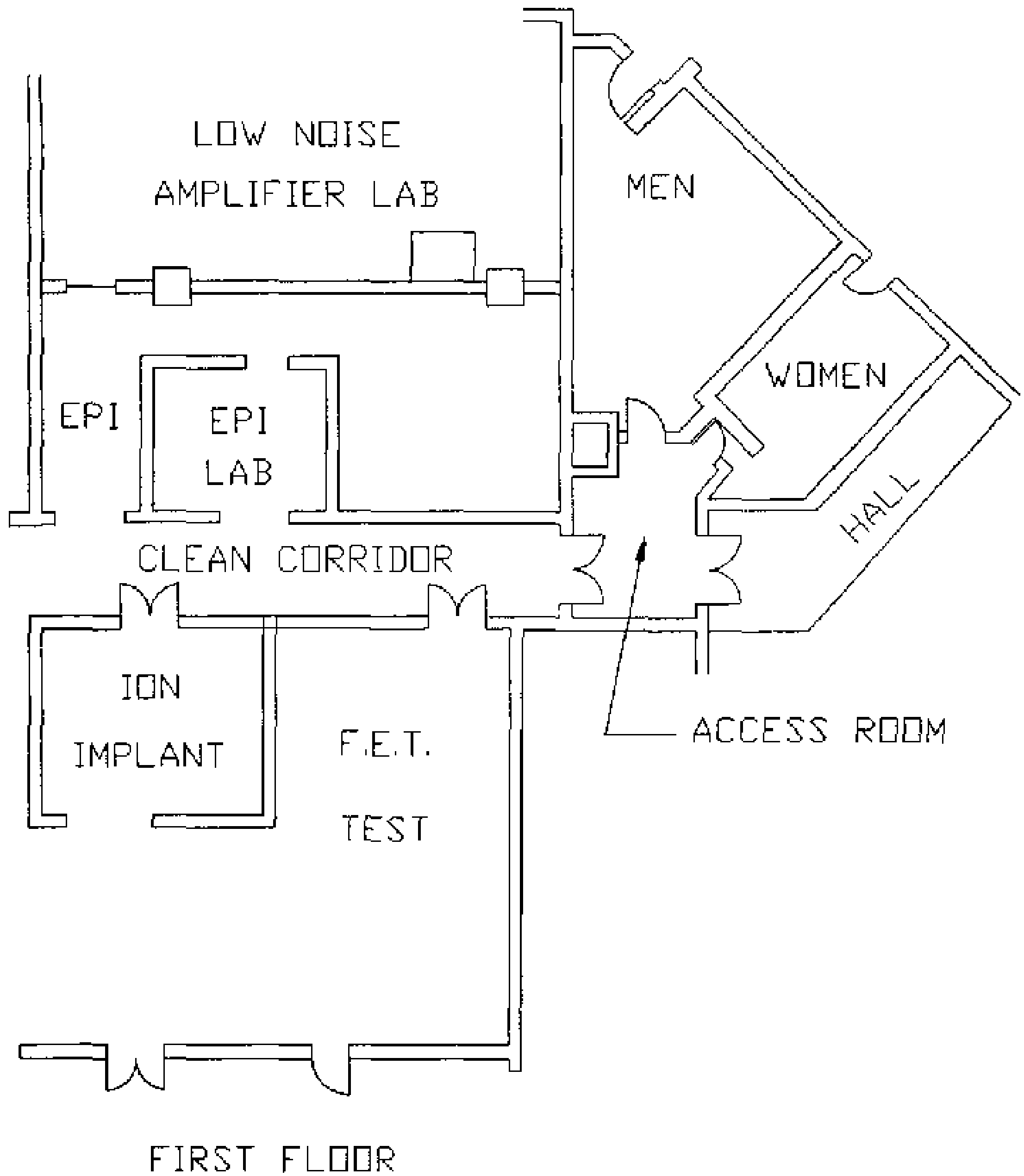


Figure 2. Plant Layout - Epitaxy and Ion Implant Areas.

condensed and the residual hydrogen is burned off as the gases exit the reaction chamber into an exhausted hood

The ion implantation process deposits dopants into a gallium arsenide wafer The dopants are ionized by electrical discharge and accelerated by passing through an electric field The beam of ions, focused on the target wafer, strikes the wafer and ions are embedded at various depths depending upon their acceleration Silicon tetrafluoride is the gaseous dopant used at M/A-COM The doped wafers are annealed by heating them in a dilute arsenic atmosphere furnace to relieve implantation-induced stress in the crystal lattice

Photolithographic processes are used to transfer circuit patterns on a photographic negative (mask) to the surface of the wafer Wet etching is also performed using hydrochloric or nitric acids and small amounts of hydrogen peroxide For the metallization process, conductive metals such as gold, titanium, or platinum are deposited on the wafer in a vacuum The deposited metal links the circuits on the wafer together in order for them to be functional The wafers are then thinned and, finally, scribed to separate the individual devices on the wafer

LEC Cleaning

The cleaning of the crystal puller is an integral part of the LEC process The crystal pullers are cleaned following each production run by one or more of the LEC operators on duty The operator dons a North or other brand full-face air-purifying respirator containing a NIOSH-approved HEPA filter, organic vapor combination cartridge The operator also wears a disposable Tyvek® coverall with bootlets, head covering, safety glasses, and rubber gloves while cleaning All internal surfaces of the puller are vacuumed with a HEPA-filtered vacuum cleaner and then scrubbed with a Scotch Brite® cleaning pad and isopropyl alcohol This entire cleaning procedure is approximately a two-hour operation, performed two times per week

To clean the puller, a cart holding tools, towels, Kim Wipes®, and isopropyl alcohol is rolled into the LEC puller room The puller is completely disassembled Bolts are removed with an air-powered wrench and the bottom section of the puller is lowered A Nilfisk HEPA-filtered vacuum cleaner (Model No GS0115) is used to clean the lower section of the puller and the bottom of the upper cavity The graphite insulation is removed and cleaned with towels and isopropyl alcohol Each graphite piece is scrubbed with a pad containing a very fine abrasive and vacuumed (HEPA) The graphite liners are then placed in the ventilated contamination control box shown in Figure 3 (The control box, originally located on a table where it would get dirty during cleaning, was moved to a wall)

The cleaning operator loosens the bolts to the heater, scrubs each bolt, and places them in the control box He scrubs the heater with Norton® pads, wipes each part with Kim Wipes®, and places the parts in the control box The Kim Wipes® and pads are placed into a hazardous waste bag for compaction

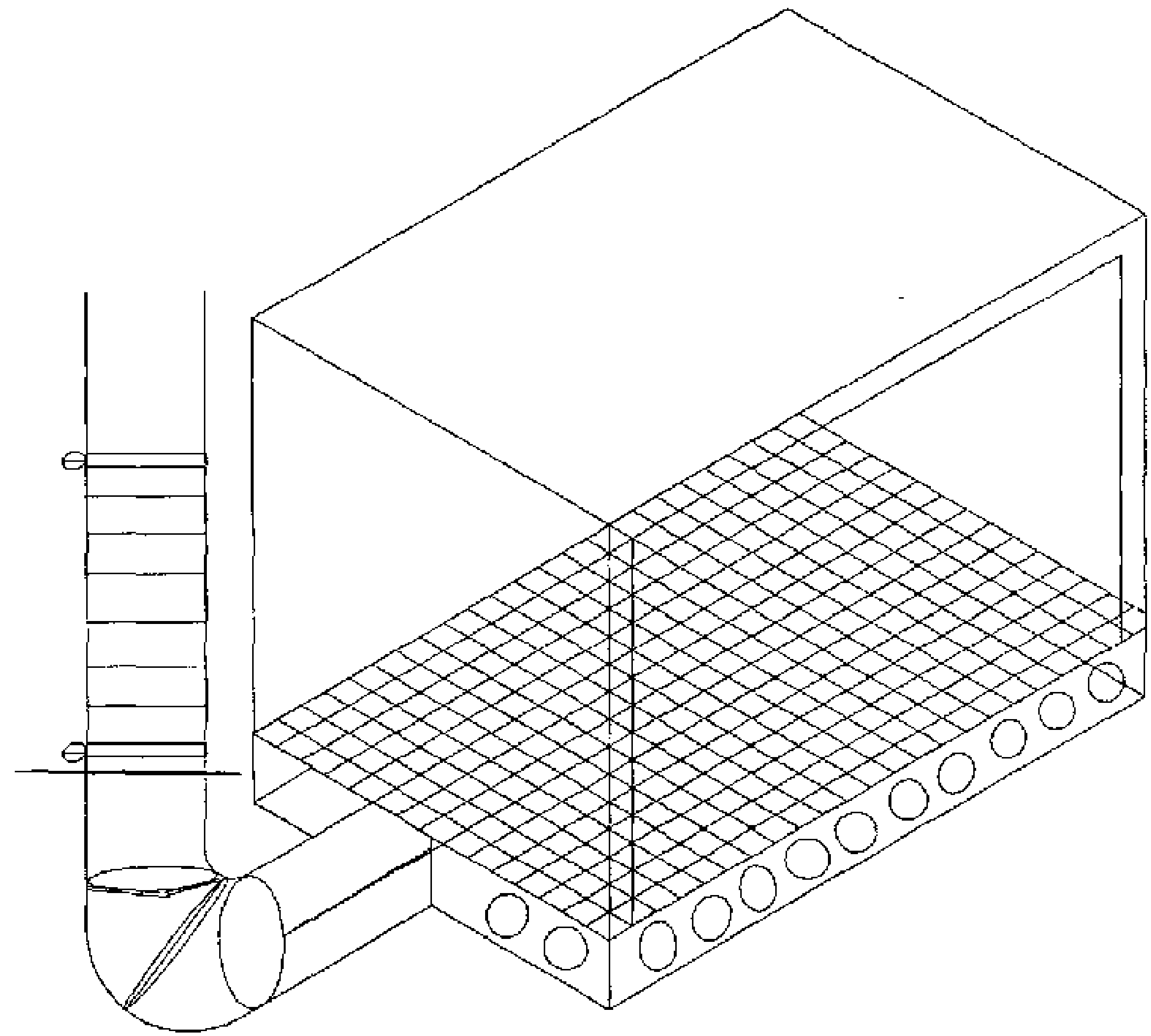


Figure 3. Ventilated Contamination Control Box Located in each LEC Puller Room.

The operator proceeds to clean the inside walls of the stainless steel puller using the pads, then vacuums the puller base, disassembles small parts of the puller base, raises the base, fastens the bolts on the base, unscrews the bolts on the top, and lowers the base He vacuums and scrubs the seed holder and the interior of the middle sleeve The optical quartz lens is removed and taken to the laboratory The top of the puller is disassembled and the parts of the puller top that are not removed are vacuumed, scrubbed, and wiped The operator leaves the puller room and manipulates the puller rods from the control panel To prevent contamination of the control area, the operator either puts a clean pair of gloves on over the old gloves or removes and disposes of his gloves as he exits the puller room The operator returns (with a new pair of gloves if needed) and finishes scrubbing and wiping the puller interior The puller is reassembled The O-rings are greased and installed in the puller (The operator removes the gloves to apply the grease) The puller, which is on a hydraulic lift, is raised at the end of cleaning to the operating height After cleaning, the LEC crystal puller is baked-out

Process Rooms

Each crystal puller at M/A-COM is located in its own room (see Figure 1) which is under negative pressure with respect to the control panel area Clean HEPA filtered air is provided to the control area and is pulled through the crystal growth room doors and exhausted The air is changed in both areas at a rate of 1 8 air changes per minute

A Plexiglas® contamination control box with a nitrogen purge is employed at M/A-COM as a crucible loading station in the LEC area The gallium and arsenic are loaded into a crucible located within the glove box A hazardous waste barrel is provided underneath the glove box for accidental arsenic spills Also in the LEC production area are wet chemical stations equipped with exhaust hoods

In the LEC process at M/A-COM, cleaning the crystal puller presented the area of greatest risk to the worker and showed the highest arsenic exposures Therefore, an air shower system was designed and installed above the crystal puller to reduce arsenic levels Company staff state that the air shower system is designed to move air down over the puller at a rate of 100 feet per minute The worker stands on a grate directly underneath the air shower system while cleaning the puller M/A-COM designed and installed this air shower system to reduce the arsenic exposure levels during cleaning M/A-COM has designated the crystal pulling rooms as a regulated area under CFR 1910 1018

M/A-COM also follows specific housekeeping guidelines Mops and pails are not allowed to leave the regulated crystal pulling area In addition, the walls and columns in the crystal pulling and epitaxy rooms are vacuumed once a month

The surface (flat) grinding machine is provided with an enclosed, wet, recirculation system with a settling tank This system is vented to wet, packed scrubbers on the roof The automated saws are partially enclosed and also vented to scrubbers on the roof

The epitaxial growth operation is conducted in a clean room designed as Class 10,000, however, M/A-COM actually operates the clean rooms as Class 1,000 All of the epitaxial growth process takes place in an enclosed ventilation hood The air in the epitaxial control room is changed at a rate of 1 3 air changes per minute, by the means of a once through air supply system The primary purpose of the clean room is to prevent contamination of the wafers

Both the crystal pulling area and the epitaxy laboratory are equipped with an emergency exhaust system, which the operator can activate at any time by pushing a red panic button

While in use, arsine (10 3% concentration) and silane (1,000 ppm) gases are stored in cabinets equipped with a sprinkler system and ventilated at a rate of 150 cubic feet per minute All welded stainless steel lines are used from enclosure to enclosure for the transportation of these toxic and flammable gases

A litmus indicator is used on the sealed arsenic trichloride ampoules for the purpose of indicating ampoule leakage or breakage

The labs have separate drains for solvent and acid/caustic wastes The acid/caustic wastes are neutralized in an industrial waste treatment system The solvent wastes are piped to a 1,500-gallon solvent waste storage tank This system reduces the opportunity for chemicals to be accidentally poured into the sanitary sewers

EVALUATION CRITERIA

Chronic exposure to arsenic may cause malaise, fatigue, peripheral neuropathy, and perforation of the nasal septum Arsenic is also suspected of causing skin and respiratory tract cancer [1] Stringent controls are required to assure that exposures to arsenic are less than the current OSHA permissible exposure limit (PEL) of 10 $\mu g/m^3$, the OSHA action level of 5 $\mu g/m^3$, and the NIOSH recommended exposure limit (REL) of 2 $\mu g/m^3$ The plant must establish regulated areas where inorganic arsenic exposures exceed the PEL These regulated areas must be demarcated and segregated from the rest of the workplace, access must be limited to authorized persons, and appropriate respirators must be worn [2]

The OSHA PEL for arsine is 200 $\mu g/m^3$, the NIOSH REL is 2 $\mu g/m^3$, the same as for arsenic [2,3] Arsine is an extremely toxic gas that can produce massive hemolysis and renal failure, and exposures as low as 10 ppm have caused coma and death Early effects from an exposure are characterized by giddiness, headache, shivering, and abdominal pain [4] Arsine has a slight garlic odor which is only detectable above safe levels [1]

At M/A-COM, some of the solvents and gases used include methanol, fluorocarbon compounds, silane, and a very small amount of trichloroethylene (TCE) in the wafer manufacturing process Methanol can cause optic nerve damage and blindness However, these symptoms occur principally after oral-ingestion of methanol and rarely after inhalation Fluorocarbon compounds can produce mild irritation to the upper respiratory tract Mild central nervous system depression may also occur in cases of exposure to very high concentrations of fluorocarbons. Silane is a pyrophoric gas and therefore presents a fire and explosion hazard.[4] Acute exposure to TCE depresses the central nervous system and produces such symptoms as headache, dizziness, fatigue, and nausea.[1] Hydrochloric and nitric acids used in etching processes can cause severe burns to the skin on contact; fumes of these acids can damage the respiratory tract. The NIOSH REL and OSHA PEL are 5,000 $\mu g/m^3$ (TWA) for HNO_3. The PEL for HCl is 7,000 $\mu g/m^3$ (15-minute ceiling); there is no NIOSH REL.[2,5]

III. METHODOLOGY

Air Sampling and Analysis

Personal and area samples for arsenic and gallium were collected on 37 mm diameter cellulose ester, 0.8 μm pore size filters. Prior to the conduct of the survey, the filters were pretreated with a sodium carbonate/glycerol solution and dried by drawing a sufficient volume of air through them to minimize the initial pressure drop.

Two types sampling trains were used for the collection of arsenic and gallium, as described in Table 1. One consisted simply of a treated filter and a DuPont P-4000 pump operated at a flow rate of approximately 1.5 liters per minute (Lpm). The other consisted of a treated filter in series with a charcoal tube and a DuPont P-2500 pump operated at a flow rate of approximately 0.5 Lpm. This latter was employed because in the presence of heated arsenic sources, arsenic trioxide vapors or volatilized arsenical materials may be present in the air. Vapors may pass through conventional filters; hence, monitoring with only the filter could underestimate the total arsenic exposures. The charcoal tubes consisted of 400 mg of activated coconut-based charcoal in the main section and 200 mg of activated charcoal in the backup section. A larger (400 mg/200 mg) charcoal tube was used instead of the 100 mg/50 mg charcoal tube provided for in NIOSH Method 6001[6] in order to allow the 0.5 Lpm flow rate. For personal samples, the charcoal tube was placed in a sorbent tube holder in series with a treated filter. The tube holders were pretested for leaks prior to the conduct of the survey.

Arsine vapors were collected using the same sampling train at a flow rate of approximately 0.1 Lpm using DuPont P-200 pumps. The prefilter was analyzed for arsenic and gallium.

Sampling duration was based on the adsorptive capacity of the tubes for the contaminant to be sampled. Approximate full-shift samples were taken with the filter cassettes; however, the charcoal tubes were changed every 2 to 3 hours in order to avoid breakthrough. During operations that lasted only part of the shift, such as annealing, shorter (2- to 6-hour) samples were taken. Additionally, short-term sampling for arsenic and gallium was performed specifically for the duration of the LEC cleaning operation.

Air sampling was also performed for various acids. Mineral acid adsorption tubes (400 mg/200 mg) were used to sample for nitric and hydrochloric acids with DuPont P-2500 pumps at a flow rate of approximately 0.5 Lpm.

Table 1. Sampling and Analytical Methods

Sample Train	Flow Rate (lpm)	Analyte	Analytical Method[6,7]
Filter	1.5	Arsenic, Gallium	Graphite Furnace AA According to NIOSH Method 7901
Filter and Charcoal Tube	0.5	Arsenic, Gallium (filter) Arsenic (tube)	Graphite Furnace AA According to NIOSH Method 7901 (filter) Graphite Furnace AA According to NIOSH Method 6001 (tube)
Prefilter and Charcoal Tube	0.1	Arsenic, Gallium (filter) Arsenic (tube)	Graphite Furnace AA According to NIOSH Method 7901 (filter) Graphite Furnace AA According to NIOSH Method 6001 (tube)

All filter samples for arsenic and gallium were analyzed by graphite furnace atomic absorption spectrophotometry (AA) in accordance with NIOSH Method 7901 [7] The graphite furnace AA was found to be more appropriate for the desired sensitivity than the ICP method for these metals For samples analyzed for arsenic and gallium, the limit of detection (LOD) ranged from 0 03 to 0 1 μg/filter for arsenic and 0 02 to 0 2 μg/filter for gallium, depending on the specific analytical batch The limit of quantitation (LOQ) ranged from 0 08 to 0 32 μg/filter for arsenic and 0 06 to 0 52 μg/filter for gallium Charcoal tubes were analyzed for arsenic by NIOSH Method 6001[6] by means of graphite furnace AA The LOD for the charcoal tubes ranged from 0 02 to 0 05 μg/tube and the LOQ ranged from 0 051 to 0 13 μg/tube for arsenic NIOSH Method 7903[7] was employed for the analysis of the mineral acid tubes The LOD was 1 0 μg/tube for hydrochloric acid and 0 5 μg/tube for nitric acid The LOQ was 3 6 μg/tube for hydrochloric acid and 1 6 μg/tube for nitric acid

Wipe Samples

Wipe samples were also taken to measure arsenic surface contamination Wearing polyethylene gloves, an investigator removed a Whatman 42, 7 cm (1 8-inch) diameter filter from the box The filter was moistened with 0 4 milliliters of triple distilled deionized water using a pipette Areas of 100 cm^2 were wiped with the moistened filter Plexiglas® templates or masking tape were employed to delineate the areas The filter was folded in half with the exposed side in and folded again to form a 90° angle in the center of the filter It was placed, angle first, in a clean glass vial and capped for submission to the laboratory In order to determine the degree of variability in a measurement, side-by-side replicate wipe samples were taken for several of the initial wipes In addition, for several samples, the same area was rewiped with another filter paper in order to determine a collection efficiency

Wipe samples were collected in the LEC and grinding/sawing areas These samples were analyzed by graphite furnace AA in accordance with NIOSH Method 7901 [7] The LOD for arsenic was 0 08 μg/filter and the LOQ was 0 25 μg/filter

OBSERVATIONS

During the sampling survey, effective work practices and use of personal protective equipment were documented, especially during the LEC cleaning Ventilation measurements were taken using either a Kurz or a TSI hot-wire anemometer

IV CONTROL TECHNOLOGY

PRINCIPLES OF CONTROL

Occupational exposures can be controlled by the application of a number of well-known principles including engineering measures, work practices, personal protection, and monitoring These principles may be applied proximate to the hazard source, to the general workplace environment, or at the point of occupational exposure to individuals Controls applied at the source of the hazard, including engineering measures (material substitution, process and equipment modification, isolation or automation, local ventilation) and work practices, are generally the preferred and most effective means of control, both in terms of occupational and environmental concerns Controls which may be applied to hazards that have escaped into the workplace environment include dilution ventilation, dust suppression, and housekeeping Control measures may also be applied near individual workers, including the use of remote control rooms, isolation booths, supplied-air cabs, work practices, and personal protective equipment

In general, a system comprised of the above control measures is required to provide worker protection under normal operating conditions as well as under conditions of process upset, failure, and/or maintenance Process and workplace monitoring devices, personal exposure monitoring, and medical monitoring are important mechanisms for providing feedback concerning effectiveness of the controls in use Ongoing monitoring and maintenance of controls to ensure proper use and operating conditions, and the education and commitment of both workers and management to occupational health are also important ingredients of an effective control system

These principles of control apply to all situations, but their optimum application varies from case to case The application of these principles are discussed below

RESULTS/DISCUSSION

The parameters and analytical results of individual samples are shown in the appendices to this report

Arsenic Air Samples

Analytical results for arsenic on 23 field blanks were all less than the LOQ and 21 were less than the LOD Similar analyses performed on 13 charcoal tube field blanks were all below the LOD Therefore, no blank corrections were made to the analytical results of samples collected on either the filters or the charcoal tubes

Results of personal sampling for arsenic for four gallium arsenide processes are presented in Table 2a These include LEC, LEC cleaning, grinding/sawing, and epitaxy The arithmetic and geometric mean arsenic concentrations in LEC, grinding/sawing, and epitaxy are compared in Figure 4 The average exposure during the LEC process was 0 9 $\mu g/m^3$ except during cleaning Four of the five samples were taken on the same day shift operator during four days of sampling Arsenic exposures during LEC cleaning averaged 426 $\mu g/m^3$ and ranged from 125 to 1030 $\mu g/m^3$ A typical LEC puller cleaning took 2 to 3 hours Three workers were sampled over two days during LEC puller cleaning One worker, who was sampled on two different days, had an average personal exposure concentration to arsenic of 150 $\mu g/m^3$, a second worker had a personal exposure concentration of 380 $\mu g/m^3$, but a third worker had an exposure of 1,030 $\mu g/m^3$ Either individual work practices or the particular puller cleaned may have contributed to this seven-fold difference in personal sample concentrations A full face (organic vapor/toxic particulate, dual cartridge) air-purifying respirator was worn during LEC cleaning

Table 2a. Personal Exposures to Total Arsenic by Process

Area Worked	Number of Samples	Average Sample Duration (min)	Arsenic Concentration*		
			Arithmetic Mean (ug/m^3)	Geometric Mean (ug/m^3)	Range (ug/m^3)
LEC	5	425	0.9	0.6	0.2 - 2.1
LEC cleaning	4	177	426	304	125 - 1030
Grinding/Sawing	3	155	1.6	1.5	1.0 - 2.6
Epitaxy/Annealing	4	299	< 2.4	< 2.3	<1.7 - <3.4

OSHA PEL	10 ug/m^3
OSHA Action Level	5 ug/m^3
NIOSH REL	2 ug/m^3

* Sum of arsenic collected on filter and charcoal tubes.

Table 2b. Personal Exposures to Total Arsenic by Process

Area Worked	Number of Samples	Average Sample Duration (min)	Arsenic Concentration*		
			Arithmetic Mean (ug/m^3)	Geometric Mean (ug/m^3)	Range (ug/m^3)
LEC	0				
LEC cleaning	0				
Grinding/Sawing	1	141	4.4	4.4	
Ion Implantation	4	248	<0.1	<0.1	<0.1 - <0.2

OSHA PEL	10 ug/m^3
OSHA Action Level	5 ug/m^3
NIOSH REL	2 ug/m^3

* Arsenic collected on filters only.

ARITHMETIC VS GEOMETRIC MEAN ARSENIC EXPOSURES

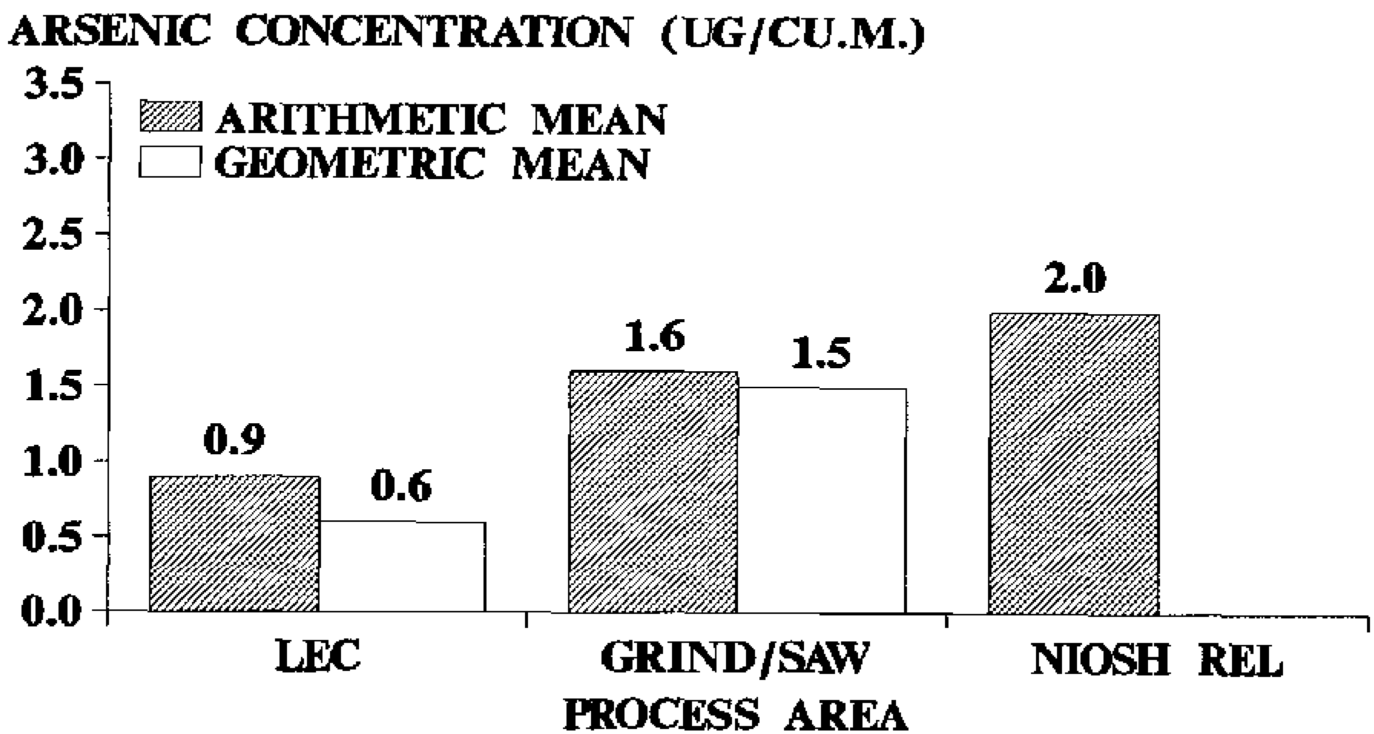


Figure 4

In the grinding/sawing area, arsenic exposures averaged 1 6 $\mu g/m^3$ and ranged from 1 0 to 2 6 $\mu g/m^3$ (Table 2a) A single personal sample for arsenic, collected on a grinding/sawing operator using a filter without a charcoal tube, was 4 4 $\mu g/m^3$ as shown in Table 2b Thus, the overall arithmetic mean exposure for personal samples in grinding/sawing, collected using both types of sampling trains, was 2 3 $\mu g/m^3$

All of the personal samples for vapor phase arsenic collected in the epitaxial area were below the LOD which averaged 2 4 $\mu g/m^3$ These results indicate that the current controls for arsine/arsenic in epitaxy most likely prevent routine exposure to airborne arsenic and arsine Personal samples for arsenic collected on the operator for the ion implantation process using a filter only sampling train were all below the LOD which ranged from 0 1 to 0 2 $\mu g/m^3$ (Table 2b) This worker also spent considerable time in the epitaxy area which is across the hall from the ion implantation process, but within the main clean room zone

Only during LEC cleaning were time-weighted average (TWA) personal arsenic exposures above the NIOSH REL of 2 $\mu g/m^3$ and above the OSHA action level of 5 0 $\mu g/m^3$, as shown in Table 2a Although respirators are worn during LEC cleaning, prudent practice indicates that efforts should also be made to improve engineering controls and work practices during this activity In the grinding/sawing area, two of four personal samples were above the NIOSH REL, but all were less than the OSHA action level Because several samples showed arsenic levels above the NIOSH REL, additional monitoring for arsenic is recommended in the sawing/grinding area

Samples in the LEC during routine operation and in epitaxy were collected for almost a full shift (5 to 7 hours), however, sampling times during LEC cleaning and in grinding/sawing were generally under 3 hours Cleaning an LEC puller requires about 3 hours, in grinding/sawing, workers were sampled for only a half day on the first day and were willing to wear the sampler only for half-days during the remainder of the survey

Area arsenic levels for each process area studied are shown in Tables 3a and b The former shows results for samples collected using a filter followed by a charcoal tube, and the latter are filter only sample results Figure 5 compares average personal arsenic concentrations (filter plus tube samples) with average area concentrations (filter plus tube samples) for the LEC, grinding/sawing, and epitaxy process areas as well as background arsenic concentrations taken in halls/offices away from the process areas Personal concentrations were a little higher than area arsenic concentrations, however, in epitaxy the difference in average arsenic concentrations was due to a higher limit of detection for personal samples than for area samples

Arithmetic means of arsenic sample concentrations in the LEC puller rooms were 0 3 $\mu g/m^3$ (Table 3a) and 0 2 $\mu g/m^3$ (Table 3b) indicating very low emissions of arsenic during routine LEC operation All arsenic concentrations at the LEC control panels, which are located just outside the puller rooms, were below the LOD, which averaged 0 3 $\mu g/m^3$ (Table 3a), and below the LOD of 0 1 $\mu g/m^3$ for the filter only samples (Table 3b) Arsenic concentration in the LEC load room averaged 0 9 $\mu g/m^3$ (Table 3a) and

Table 3a. Area Sample Total Arsenic Concentrations by Process

Area Worked	Number of Samples	Average Sample Duration (min)	Arsenic Concentration* Arithmetic Mean (ug/m³)	Geometric Mean (ug/m³)	Range (ug/m³)
LEC					
Pullers	13	412	0.3	0.3	0.1 - 0.5
Control Panel	4	422	<0.3	<0.3	<0.3 - <0.4
Load Room	2	176	0.9	0.9	0.7 - 1.1
LEC Cleaning					
Pullers	4	186	58	51	26 - 107
Control Panel	3	202	<0 8	<0.7	<0.4 - <1.2
Grinding/Sawing	4	392	1.1	1.0	<0.4 - 1 8
Epitaxy/Annealing	11	346	<1.1	<0.8	<0.2 - <2.6
Hall between gowning and clean rooms	2	411	<1.6	<1.6	<1.5 - <1.6
Hall/office across from LEC	4	398	0.4	0.4	<0.4 - 0.6

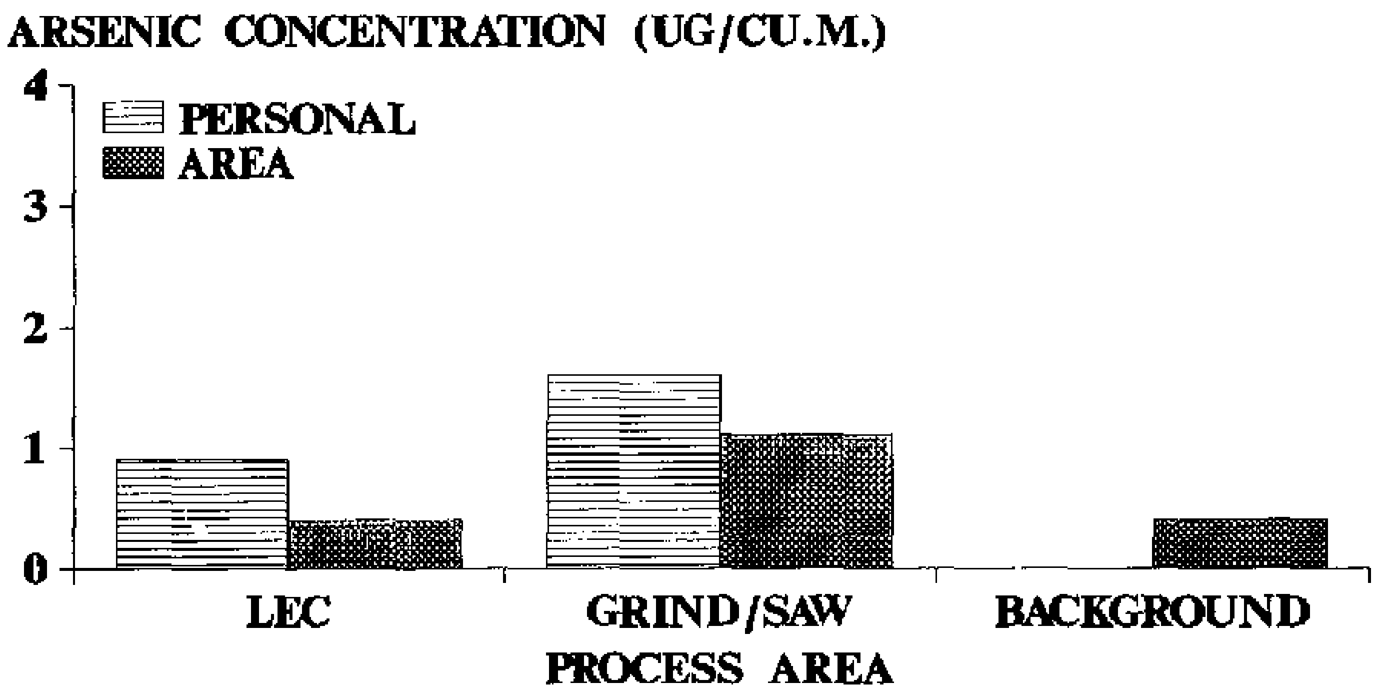
* Sum of arsenic collected on filter and charcoal tubes.

Table 3b. Area Sample Total Arsenic Concentrations by Process

Area Worked	Number of Samples	Average Sample Duration (min)	Arsenic Concentration*		
			Arithmetic Mean (ug/m^3)	Geometric Mean (ug/m^3)	Range (ug/m^3)
LEC					
Pullers	12	414	0.2	0.2	0.1 - 0.7
Control Panel	4	422	<0.1	<0.1	<0.1
Load Room	2	176	1.2	1.0	0.7 - 1.6
LEC Cleaning					
Pullers	3	198	76	75	61 - 100
Control Panel	3	202	<0.2	<0.2	<0.3
Hall across from LEC	3	211	<0.2	<0.2	<0.1 - <0.3
Grinding/Sawing	10	316	2.1	0.8	<0.1 - 7.0
Epitaxy/Annealing	1	284	<0.2	<0.2	<0.2
Ion Implantation	4	324	<0.1	<0.1	<0.1 - <0.2
Hall/office across from LEC	8	346	0.2	0.2	<0.1 - 0.4

* Arsenic collected on filter only.

PERSONAL VS AREA AVERAGE ARSENIC CONCENTRATIONS*



*Filter plus tube samples

Figure 5

1 2 $\mu g/m^3$ (Table 3b) In sampling the LEC operation, each filter only sample was paired with a filter plus charcoal tube sample

Area sample arsenic concentrations in the enclosed LEC puller rooms and at the LEC control panel were slightly lower than the LEC operators' exposure during routine operation In the LEC load room, area concentrations were comparable to the LEC operators' arsenic exposure Area sample arsenic concentrations in the puller rooms and at the control panel were about the same as levels measured in the hall and offices across from the LEC process area The arithmetic mean arsenic concentration in the hall/office across from the LEC area was 0 4 $\mu g/m^3$ (filter and tube samples) and 0 2 $\mu g/m^3$ (filter only samples)

Arithmetic means of arsenic concentrations in the grinding/sawing area were 1 1 $\mu g/m^3$ (filter plus tube) and 2 1 $\mu g/m^3$ (filter only) Higher than average concentrations were found near the operating saws, for example, two samples taken by operating saws were 4 8 and 7 0 $\mu g/m^3$ On the other hand, the highest concentrations by the edge beveler and O D grinder were 0 1 and 1 3 $\mu g/m^3$, respectively Excluding the edge beveler results, area arsenic concentrations were nine times higher on Thursday than Monday of the survey, indicating a large variability in arsenic emissions and the potential for exposures above the OSHA action level of 5 0 $\mu g/m^3$ Figure 6 shows the average area concentrations were higher for the saws than for the O D grinder and edge beveler Average area sample concentrations were comparable to personal sample concentrations in grinding/sawing

Area samples of arsenic concentrations in the epitaxy and annealing process were all below the LOD which averaged 1 1 $\mu g/m^3$ (Table 3a) The one filter only sample for arsenic in epitaxy was less than 0 2 $\mu g/m^3$ The LOD for arsenic for the area samples collected in epitaxy averaged about half the detection limit for the personal samples (2 4 $\mu g/m^3$) This is because in epitaxy all the personal samples were collected at 0 1 Lpm, while area samples were collected at both 0 1 Lpm and 0 5 Lpm

Arsenic area samples collected in ion implantation were below the LOD which averaged 0 1 $\mu g/m^3$ (Table 3b), the same as the personal sampling results Arsenic was collected on filter only samples in the ion implantation area

Area arsenic samples collected in the hall and offices, 15 to 25 feet from the LEC and grinding/sawing process rooms, showed average concentrations of 0 4 $\mu g/m^3$ (two of the four background samples had nondetected amounts of arsenic) Doors to the LEC and grinding/sawing rooms were kept closed Because arsenic levels in the LEC and grinding/sawing areas were very low, the possibility of cross-contamination between production and nonproduction areas resulting from general airflow patterns could not be ascertained

Area samples collected in the LEC puller rooms during cleaning averaged 58 $\mu g/m^3$ of arsenic (filter plus tube) and 76 $\mu g/m^3$ of arsenic (filter only) The reduction in area arsenic concentrations between the puller room and control panel area during LEC cleaning was greater than 99 percent (Figure 7) Arsenic samples at the control panels during LEC cleaning were all

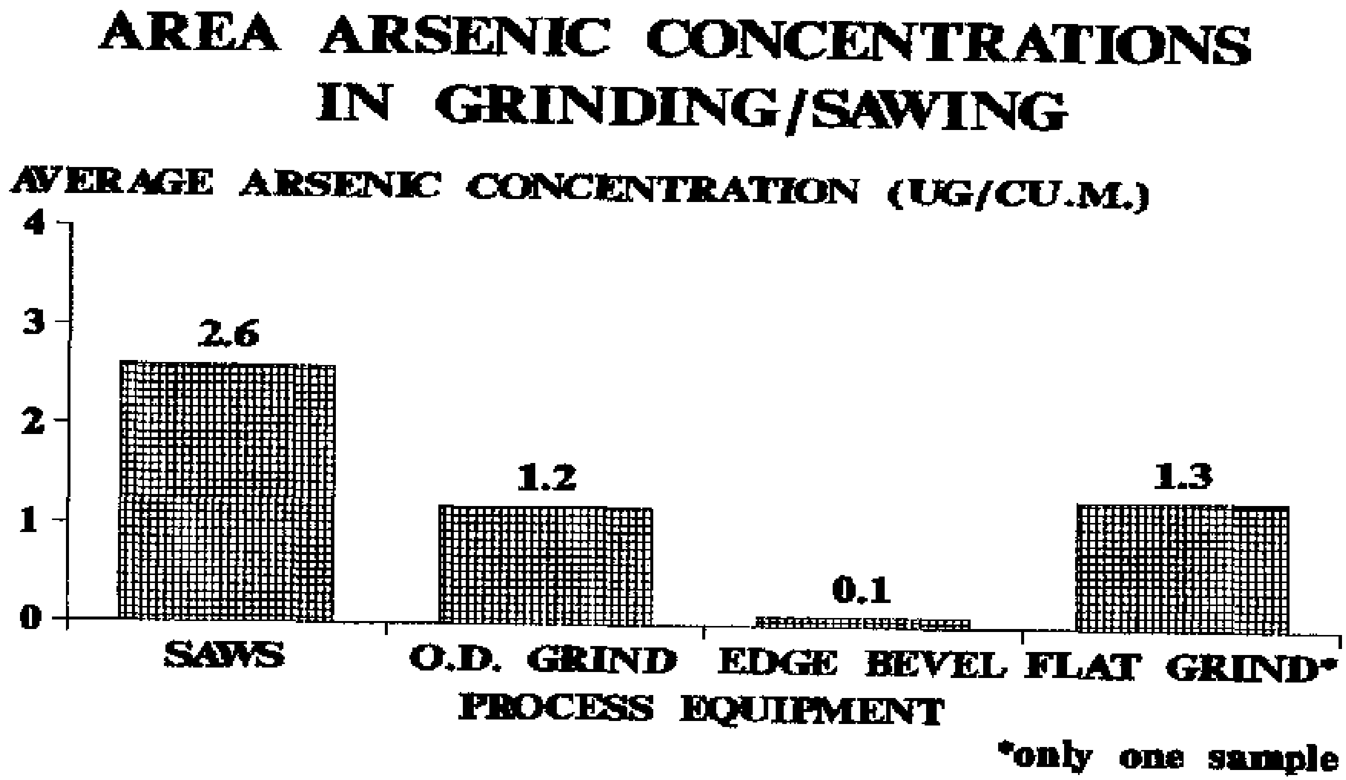

AREA ARSENIC CONCENTRATIONS
IN GRINDING/SAWING
AVERAGE ARSENIC CONCENTRATION (UG/CU.M.)
4
3
2
1
0
2.6
1.2
0.1
1.3
SAWS
O.D. GRIND
EDGE BEVEL
FLAT GRIND*
PROCESS EQUIPMENT
*only one sample

Figure 6

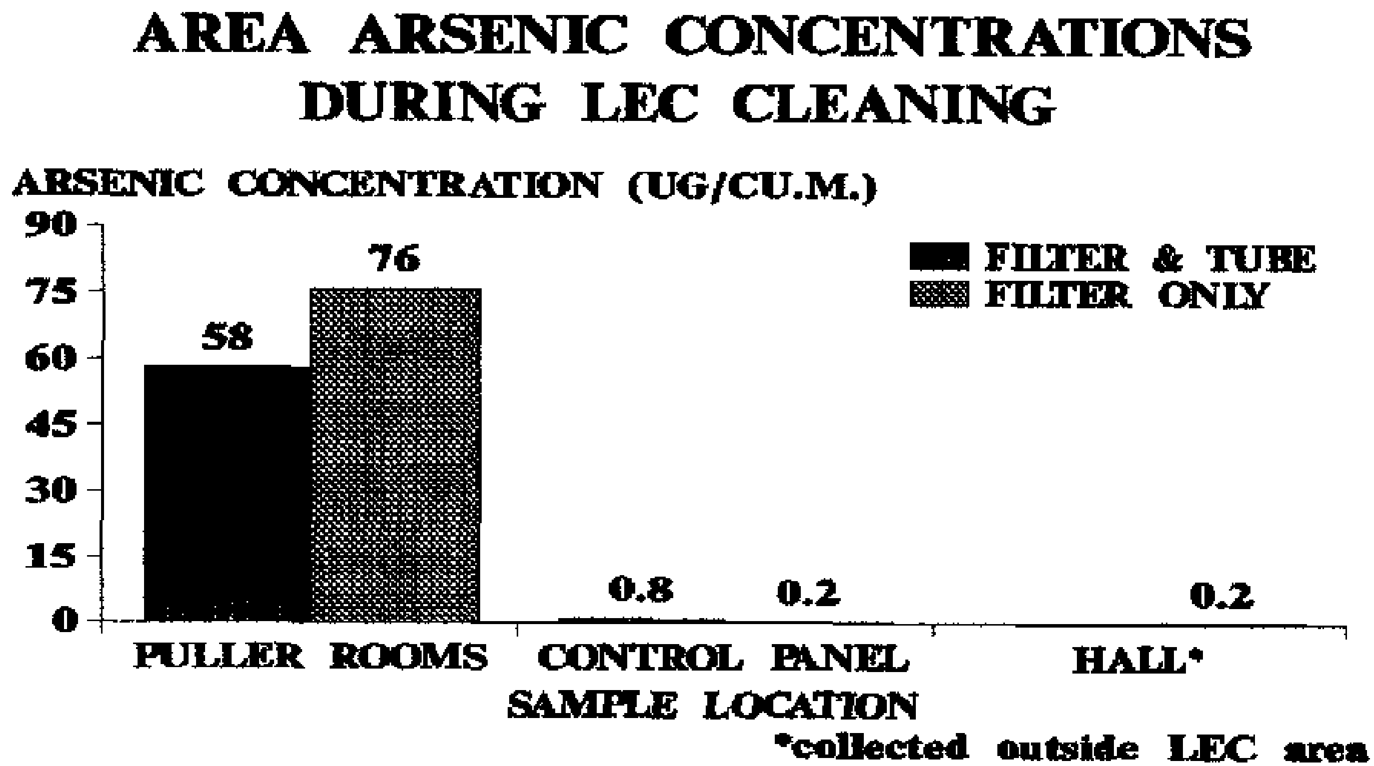

AREA ARSENIC CONCENTRATIONS
DURING LEC CLEANING
ARSENIC CONCENTRATION (UG/CU.M.)
90
75
60
45
30
15
0
FILTER & TUBE
FILTER ONLY
58
76
0.8
0.2
0.2
PULLER ROOMS
CONTROL PANEL
HALL*
SAMPLE LOCATION
*collected outside LEC area

Figure 7

below the LOD, which averaged 0.8 $\mu g/m^3$ (filter plus tube), while filter only samples averaged <0 2 $\mu g/m^3$ In the hall across from the LEC process, arsenic concentrations were below the LOD which averaged 0 2 $\mu g/m^3$ The cleaning operator occasionally went in and out of the LEC puller room during cleaning

Area sample arsenic concentrations in the puller rooms during cleaning ranged from 26 to 107 $\mu g/m^3$ and were generally lower than the LEC cleaning operators' arsenic exposures (125 to 1,030 $\mu g/m^3$) Surprisingly, arsenic exposures during LEC cleaning are inversely correlated to area sample concentrations for the same pullers For example, the LEC operator cleaning puller #7 had a personal sample concentration of 1,030 $\mu g/m^3$ (highest) and an area sample concentration of 26 $\mu g/m^3$ (lowest), while the operator cleaning puller #1 had the lowest exposure (125 $\mu g/m^3$) but the highest average area sample concentration (104 $\mu g/m^3$) Possibly, the first worker received nearly all his exposure from work practices, such as wiping and vacuuming techniques and other job tasks, while the latter workers' exposure appeared to be the result of air levels for arsenic in the puller room generated during LEC cleaning

Sample results from this survey showed that rarely did arsenic pass through the filter and collect on the charcoal tube Arsenic was found on only 4 of the 153 charcoal tubes and ranged from 0 03 to 0 15 μg These samples included two personal samples in the LEC, one personal sample during LEC cleaning, and one area sample in the LEC Two of the tubes were part of a sampling train which included detectable arsenic on the filter The amount of arsenic on the charcoal tubes for these two samples represented 0 04 and 11 percent of the total sample (filter arsenic plus tube arsenic)

Arsenic Wipe Samples

Wipe samples for arsenic were collected on various surfaces in the LEC and grinding/sawing areas These sample results, in micrograms of arsenic per 100 square centimeters ($\mu g/100\ cm^2$), are presented in Table 4 The highest arsenic levels were found on the exhaust duct work in the LEC puller rooms 2,800 $\mu g/100\ cm^2$ Arsenic surface contamination for all the other locations sampled in the LEC averaged less than 100 $\mu g/100\ cm^2$ The lowest arsenic surface contamination (13 $\mu g/100\ cm^2$) in the LEC was measured on the control console, which is located outside the puller rooms

In the grinding/sawing area, the arsenic surface contamination found on the flat grinder was 300 $\mu g/100\ cm^2$, however, this is the result of only one sample Arsenic on the O D grinder was 66 $\mu g/100\ cm^2$, but only 6 $\mu g/100\ cm^2$ on the O D grinder enclosure Arsenic surface contamination on a desk used by one of the operators was 33 $\mu g/100\ cm^2$

Blank wipe samples collected at this plant were between the LOD and the LOQ and averaged 0 1 μg

Table 4. Wipe Sample Results for Arsenic

Process	Sample Location	Number of Samples	Sample Area (cm^2)	Arsenic Surface Contamination (ug/100 cm^2)
LEC	Control console for LEC pullers	4	100	13
	Shelf next to ventilated control box (puller room)	5	100	47
	Top and side of exhaust duct work (puller rooms)	5	100	2,800
	Floor in front of LEC puller	1	100	64 (repeat 25)
	Top of load room dry box	1	100	35
	Top of bench	2	100	84
Grinding/ sawing	Front of O.D. grinder enclosure	1	100	5.6
	Front of O.D. grinder	2	100	66
	Flat grinder	1	100	300
	Workstation near saw	2	100	66
	Control panel for saw	1	100	45 (repeat 10)
	Top of desk	1	100	33

Gallium Air Samples

Field blank results for gallium were below a LOD of 0 2 μg/filter for 12 filters and below a LOD of 0 03 μg/filter for 11 filters None of the filter blanks contained detectable amounts of gallium, therefore, no blank corrections were made to air sample results for gallium

Gallium air sample concentrations are presented in Appendix A, Table A-3 Personal sample gallium concentrations are summarized in Table 5 for four GaAs processes and the LEC cleaning operation The highest average personal sample concentration during routine operations was found in the grinding/sawing area (2 5 μg/m^3) In the LEC area, exposures to gallium averaged 0 7 μg/m^3 and in epitaxy and ion implantation, exposures were below the average LODs of 1 2 and 0 1 μg/m^3, respectively Higher average exposures for gallium, by at least 2 orders of magnitude, were found during LEC cleaning (108 μg/m^3) There is no OSHA PEL or NIOSH REL for gallium, however, NIOSH recommends that worker exposure to gallium arsenide be controlled to the NIOSH REL for inorganic arsenic of 2 μg/m^3 (ceiling) as arsenic [2]

Area sample results for gallium are summarized in Table 6 All samples for gallium taken at the LEC control panel, in the LEC load room, and at the pullers were less than 1 μg/m^3 during routine operation Grinding/sawing area sample concentrations averaged 2 1 μg/m^3, the same as the personal sample concentrations for gallium in this area In epitaxy, ion implantation, and in the halls and offices away from GaAs processing, average gallium concentrations were less than 0 6 μg/m^3 During LEC cleaning, area gallium concentrations averaged 7 μg/m^3, which is much lower than personal sample concentrations during LEC cleaning As with the arsenic results, it appears that work practices such as wiping and scrubbing were the major source of gallium exposure during cleaning of the LEC pullers

The gallium moiety (i e , the gallium portion) of gallium arsenide is 48%, therefore, an almost one to one gallium to arsenic ratio was expected for the process areas which used predominantly gallium arsenide In all process areas sampled, except during LEC cleaning, the amount of gallium was almost the same as that of arsenic for the same filter However, during LEC cleaning the gallium concentrations averaged only 13 percent of the arsenic concentrations indicating that the puller interior is contaminated primarily with arsenic

Inorganic Acid Results

Field blank results for nitric acid were all below the average detection limit of 0 5 μg/tube, therefore, no blank corrections were made to air samples for this acid Field blanks for hydrochloric acid averaged 5 0 μg/tube and the air sample results for HCl acid were appropriately blank corrected

Area samples for hydrochloric and nitric acids were collected at the LEC wet bench over a 4-day period Average concentrations are shown in Table 7 Generally, two consecutive 4-hour samples were taken each day Nitric acid concentrations were well below the OSHA PEL and the NIOSH REL of 5,000 μg/m^3, except during the removal of a frozen ingot from the

Table 5. Personal Exposures to Gallium by Process

Area Worked	Number of Samples	Average Sample Duration (min)	Gallium Concentration* Arithmetic Mean (ug/m^3)	Geometric Mean (ug/m^3)	Range (ug/m^3)
LEC	5	389	0.7	0.3	<0.1 - 2.4
LEC cleaning	4	177	108	38	9.9 -361
Grinding/Sawing	4	152	2.5	2.3	1.6 - 4.4
Epitaxy	4	299	<1.2	<0.9	<0.6 - <2.7
Ion Implantation	4	232	<0.1	<0.1	<0.1 - <0.2
OSHA PEL none NIOSH REL none					

* Gallium collected on filters only.

Table 6. Area Sample Gallium Concentrations by Process

Process/Room	No. of Samples	Average Sample Duration (min)	Gallium Concentration* Arithmetic Mean (ug/m³)	Geometric Mean (ug/m³)	Range (ug/m³)
LEC					
Pullers	12	413	0.2	0.1	<0.1 - 0.9
Control Panel	8	422	<0.1	<0.1	<0.3
Load Room	4	176	<0 3	<0.2	<0.1 - <0.4
LEC cleaning					
Pullers	7	191	6.8	4.0	0.5 - 18
Control Panel	6	202	<0.6	<0.3	<0.1 - <1.8
Hall across from LEC	3	211	<0.4	<0.4	<0.1 - <0.6
Grinding/Sawing	14	337	2.1	1.0	<0.1 - 7.4
Epitaxy/ Annealing	12	341	<0.5	<0.3	<0.1 - 1.7
Ion Implantation	4	340	<0.1	<0.1	<0.1
Hall/office across from LEC	12	363	0.3	0.2	<0.1 - 0.5
Access room to clean area	2	411	<0.6	<0.6	<0.4 - <0.8

* Gallium collected on filter only

Table 7. Inorganic Acid Concentrations

Parameter	Unit	HCl*	HNO_3
LEC Wet Bench			
Samples	Number	4	4
Arithmetic mean	ug/m^3	1907	960
Std deviation	ug/m^3	2800	1580
Range: Low High	ug/m^3	44 6800	7 3700
Average sample duration	minutes	412	412
Epitaxy Acid Cleaning			
Samples	Number	4	4
Arithmetic mean	ug/m^3	12	3.7
Std deviation	ug/m^3	5	0.2
Range: Low High	ug/m^3	8 18	3.4 4.0
Average sample duration	minutes	380	380
OSHA PEL	ug/m^3	7,000 (ceiling)	5,000 (TWA)
NIOSH REL	ug/m^3	--	5,000 (TWA)

* Blank corrected.

crucible with aqua regia when the nitric acid concentration was 3,700 $\mu g/m^3$ Hydrogen chloride concentrations were 800 $\mu g/m^3$ or less, except for one 4-hour sample (12,600 $\mu g/m^3$) collected while removing a frozen ingot with aqua regia, this concentration exceeded the OSHA PEL of 7,000 $\mu g/m^3$ (ceiling) (NIOSH does not have an REL for hydrogen chloride) Local exhaust ventilation measurements at the acid hood showed a face velocity of 60 fpm The hydrochloric acid results indicate that the local exhaust ventilation rate at the LEC wet bench may, at times, be inadequate for the control of acid emissions such as during acid removal of a frozen GaAs ingot

In the epitaxy room, area samples for hydrogen chloride and nitric acids were collected above the acid cleaning wet station over a 4-day period Average concentrations are shown in Table 7 Generally, two consecutive 4-hour samples were taken each day Nitric and hydrochloric acid concentrations were 2 to 3 orders of magnitude below the OSHA PEL and the NIOSH REL indicating excellent control of these emissions at the acid cleaning station in epitaxy The face velocities for the epitaxy acid hood averaged 100 fpm

Ventilation

In the LEC process area, air velocity measurements were taken in the puller rooms and at the wet bench acid hood Supply and exhaust air volume rates for the air shower system in three of the LEC puller rooms are shown in Table 8 The air shower system was installed to help reduce arsenic exposures to the operator during LEC crystal puller cleaning Air supplied by an overhead vent flows downward over the operator and is exhausted through a floor grate on which the operator stands In the puller rooms, exhaust airflow rates ranged from 1,200 to 2,000 cubic feet per minute (cfm), supply air rates ranged between 2,400 and 4,700 cfm The ratio of supply air volume to exhaust air volume ranged from 1 4 for puller #3 to 2 3 for pullers #5 and #7 The exhaust volume for the LEC wet bench/acid hood was 370 cfm which provided a face velocity of 60 feet per minute (fpm)

Ventilation rates for the flat grinder, epitaxy reactor, and epitaxy acid cleaning station are shown in Table 8 The exhaust volume for the flat grinder with the door to the hood fully open was 120 cfm In the epitaxy area, the downdraft horizontal grill in front of the door to the epitaxy reactor exhausted at a rate of 500 cfm The grill opening was about 22 by 30 inches The face velocity for the acid cleaning hood in epitaxy was 120 cfm

WORK PRACTICES

A special work practice is employed by M/A-COM as part of the receiving procedure for gas cylinders which could be hazardous, such as hydrogen and arsine A snoop® test is performed as the cylinders are taken off the delivery trucks, but before acceptance into the plant If a cylinder is found leaking, it is sent back with the delivery truck Cylinders accepted into the plant are placed in ventilated cabinets A particular group of workers is designated to change the cylinders, whenever needed

Table 8. Ventilation Rates for Various Process Equipment

Process Location	Exhaust Air Face Velocity (f/m)	Supply Air Rate (cfm)	Exhaust Air Rate (cfm)	Notes
LEC puller 3		2400	1700	Downdraft
LEC puller 5		2700	1200	Downdraft
LEC puller 7 (or 1)		4700	2000	Downdraft
LEC acid hood/wet bench	60		370	
G/S flat grinder hood (door opening 3/4" x 14")	640		50	Air exhausted to 3-1/2" duct
Epitaxy reactor (exhaust grill beneath door)			500	Horizontal grill downdraft
Epitaxy acid cleaning hood	120		920	92-inch long tank

MONITORING

M/A-COM has installed an MDA continuous 24-hour monitoring system for arsine with a sample port in the epitaxy laboratory A continuous monitoring system for hydrogen is also employed

Additionally, M/A-COM hired a consultant for technical assistance with engineering controls and aspects of health and safety, and now employs a full-time engineer with these responsibilities In the regulated area, personnel monitoring for arsenic is performed on a quarterly basis

MEDICAL MONITORING

Preplacement medical examinations are conducted at M/A-COM which include a medical history, spirometry test, blood profile, and a 24-hour urine arsenic test In addition, annual medical examinations are performed and the 24-hour urine tests are periodically given for people who work in the bulk area

PERSONAL PROTECTIVE EQUIPMENT

Safety goggles, Tyvek coveralls, shoe covers, and disposable gloves are worn in the crystal growth, epitaxy, and wafer fabrication areas A full face (organic vapor/toxic particulates, dual cartridge) respirator is required during the cleaning of the crystal puller Half face respirators are also required during the loading and maintenance of the crystal puller In addition, supplied air breathing apparatus is required when adding the arsenic trichloride to the epitaxial reactor and when changing arsine cylinders

V CONCLUSIONS AND RECOMMENDATIONS

1 Arsenic exposures during gallium arsenide production for routine operations are well controlled at this plant Personal exposures during routine LEC operation were at or below the NIOSH REL of 2 $\mu g/m^3$ In grinding/sawing operations, some personal exposures to arsenic were above the NIOSH REL of 2 $\mu g/m^3$, but all were below the OSHA action level of 5 $\mu g/m^3$ Personal exposures in epitaxy were all below the LOD of the sampling and analytical method which averaged 2 4 $\mu g/m^3$, in ion implantation, all arsenic personal exposures were below the LOD which averaged 0 1 $\mu g/m^3$ Exposures in these four process areas were well below the OSHA PEL of 10 $\mu g/m^3$ for arsenic Controls for arsenic during routine operations appear to be effective, however, a potential for arsenic levels above the PEL exists in the grinding/sawing operation

2 Because personal and area arsenic concentrations were either close to or below the LOQ, comparisons were not made among the various sampling locations in the process rooms or for day to day variations in concentrations, except in the grinding/sawing room Area concentrations in grinding/sawing were higher by the saws than at the grinders and edge bevelers Also, arsenic concentrations were about 10 times higher on Thursday, the fourth day of the survey, than on Monday, in part because two saws were operated on Thursday and one on Monday The high variability in arsenic concentrations in grinding/sawing could result in excessive arsenic

exposures on some days but not others, therefore, frequent or worst case monitoring for arsenic is recommended for this operation

3 High levels of arsenic were found during the LEC cleaning operation Air-purifying respirators with a full mask were worn in this area during LEC reactor cleaning NIOSH maintains, that to protect against exposure to workplace carcinogens, respirators " should consist of supplied-air, full-facepiece, positive-pressure respirators equipped with an emergency self-contained breathing apparatus The following respirators are recommended a self-contained breathing apparatus with a full facepiece operated in a pressure-demand mode, or a supplied-air respirator with a full facepiece operated in a pressure-demand mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand mode "[8] OSHA requirements for respiratory protection also specify the use of an air-supplied respirator if an operator's TWA arsenic exposure exceeds 1000 $\mu g/m^3$ (This is equivalent to a protection factor of 100 given the OSHA PEL of 10 $\mu g/m^3$)

4 For the four LEC crystal puller cleaning operations monitored in this study, the cleaning operators' arsenic exposures varied by an order of magnitude These differences may have occurred because some crystal pullers were more difficult to clean than others, and/or because of individual work practices among the three cleaning operators The two arsenic exposures for the operator who cleaned two pullers, differed only by 40%, indicating the effect of differences between these two particular pullers on arsenic exposures was minor

5 The LEC cleaning operators' exposure to arsenic should be reduced by controlling emission sources during cleaning Major potential sources of arsenic emissions include wiping the inside walls of the pullers with abrasive pads, unbolting the LEC crystal puller using an air-powered wrench, and dropping the HEPA-filter vacuum hose on the floor Wet wiping, applying local exhaust ventilation while wiping and removing graphite liners and other internal parts, and wet wiping the contaminated section of the vacuum hose between each use should reduce emissions of arsenic Good practices used by M/A-COM personnel during LEC cleaning included transferring liners and internal parts of the crystal puller to a ventilated hood, isolating individual pullers, removal and disposal of gloves (or putting a clean pair of gloves on over the old gloves) when the operator exits the puller room to prevent contamination of the control area, and the use of a hydraulic lift to lower the puller for cleaning and return it to the operating height after cleaning Isolation of the pullers in individual cells appears to protect workers in the control area and other LEC areas during puller cleaning Need less supply air or more exhaust for air shower to be effective

6 At M/A-COM, almost no arsenic was collected on the charcoal tubes following a filter Arsenic was found on only 2 6% of the 153 charcoal tubes Thus, nearly all the arsenic at this plant would be collected using the traditional filter only sampling method for arsenic

7 Relatively high levels of arsenic surface contamination were found on top of the exhaust duct work in the LEC puller rooms, the arsenic levels were at least an order of magnitude lower on the surfaces of the remaining areas sampled in the LEC and elsewhere Since protective clothing is required in the puller rooms, this contamination should not increase worker exposure However, if the puller rooms are ever modified or dismantled, the rooms should be decontaminated first

8 Sampling results for hydrochloric acid indicate that the local exhaust ventilation rate at the LEC wet bench may, at times, be inadequate for the control of acid emissions such as during acid removal of frozen GaAs ingots Nitric and hydrochloric acid results indicate excellent control of these emissions at the acid cleaning station in epitaxy

VI REFERENCES

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6 NIOSH Method 6001 (Arsine) NIOSH Manual of Analytical Methods Third Ed , Vol 2 Cincinnati, OH U S Dept Health and Human Services DHHS (NIOSH) Publication No 84-100 May 15, 1985

7 NIOSH Methods 7901 (Arsenic Trioxide), 7903 (Inorganic Acids) NIOSH Manual of Analytical Methods Third Ed , Vol 1&2 Cincinnati, OH U S Dept Health and Human Services DHHS (NIOSH) Publication No 84-100 February 15, 1984

8 NIOSH ALERT Request for Assistance in Reducing the Potential Risk of Developing Cancer from Exposure to Gallium Arsenide in the Microelectronics Industry U S Dept of Health and Human Services DHHS (NIOSH Publication No 88-100) Cincinnati, Ohio October, 1987

VII APPENDIX A

LIST OF ABBREVIATIONS

A	- AREA SAMPLE
ANNEA	- ANNEALING PROCESS
AT	- ACID TUBE
BCKGR(D)	- LOCATION OUTSIDE PROCESS ROOM
CLEC	- CLEANING LEC PULLERS
CONC	- CONCENTRATION
CONSO(L)	- CONSOLE
CT	- CHARCOAL TUBE
DET	- DETECTION
EPI	- EPITAXY ROOM
F	- AA FILTER
GS	- GRINDING AND SAWING ROOM
ION	- ION IMPLANTATION
LEC	- LEC ROOM
LOAD R	- LOAD ROOM
nd	- NOT DETECTABLE
nq	- NOT QUANTIFIED
P	- PERSONAL SAMPLE

Table A-1 Individual Filter and Charcoal Tube Sample Results

Date	Sample Number	Media	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det Limit	Arsenic mass (ug)	Arsenic Conc (ug/m3)	Det Limit	Gallium mass (ug)	Gallium Conc (ug/m3)
06/15/87	5103	F	P	LEC	BH	288	144 4	nq	0 03	0 21	nd	<0 04	<0 28
06/15/87	208	CT	P	LEC	BH	140	70 2	nd	<0 04	<0 57			
06/15/87	5104	F	A	LEC	P3	309	463 5		0 11	0 24	nd	<0 04	<0 09
06/15/87	5099	F	A	LEC	P3	309	155 3	nd	<0 03	<0 19	nd	<0 04	<0 26
06/15/87	202	CT	A	LEC	P3	115	57 8	nd	<0 04	<0 69			
06/15/87	211	CT	A	LEC	P3	72	36 2	nd	<0 04	<1 11			
06/15/87	209	CT	A	LEC	P3	122	61 3	nd	<0 04	<0 65			
06/15/87	5096	F	A	LEC	P5	317	159 0	nq	0 04	0 25	nd	<0 04	<0 25
06/15/87	5105	F	A	LEC	P5	317	475 5		0 12	0 25	nd	<0 04	<0 08
06/15/87	215	CT	A	LEC	P5	73	36 6	nd	<0 04	<1 09			
06/15/87	203	CT	A	LEC	P5	123	61 7	nd	<0 04	<0 65			
06/15/87	206	CT	A	LEC	P5	121	60 7	nd	<0 04	<0 66			
06/15/87	5098	F	A	LEC	P5CP	304	456 0	nd	<0 03	<0 07	nd	<0 04	<0 09
06/15/87	5102	F	A	LEC	P5CP	304	152 2	nd	<0 03	<0 20	nd	<0 04	<0 26
06/15/87	200	CT	A	LEC	P5CP	111	56 6	nd	<0 04	<0 72			
06/15/87	201	CT	A	LEC	P5CP	122	61 1	nd	<0 02	<0 33			
06/15/87	219	CT	A	LEC	P5CP	71	35 5	nd	<0 02	<0 56			
06/15/87	5100	F	A	LEC	P9	315	472 5	nq	0 03	0 06	nd	<0 04	<0 08
06/15/87	5097	F	A	LEC	P9	315	158 0	nq	0 04	0 25	nd	<0 04	<0 25
06/15/87	207	CT	A	LEC	P9	120	60 2	nd	<0 04	<0 66			
06/15/87	213	CT	A	LEC	P9	71	35 6	nd	<0 04	<1 12			
06/15/87	5087	F	P	GS	CM	141	211 5		0 92	4 35		0 93	4 40
06/15/87	5088	F	P	GS	DD	145	72 7	nq	0 09	1 24		0 13	1 79
06/15/87	404	CT	P	GS	DD	145	72 7	nd	<0 02	<0 28			
06/15/87	5076	F	A	GS	GS1	235	352 5		0 22	0 62		0 34	0 96
06/15/87	5084	F	A	GS	GS2	237	118 7	nd	<0 03	<0 25	nq	0 06	0 51
06/15/87	403	CT	A	GS	GS2	144	72 1	nd	<0 02	<0 28			
06/15/87	400	CT	A	GS	GS2	93	46 6	nd	<0 02	<0 43			
06/15/87	5079	F	A	GS	GS3	240	360 0	nd	<0 03	<0 08	nd	<0 04	<0 11
06/15/87	5080	F	P	EPI	SM	146	14 6	nd	<0 03	<2 05	nd	<0 04	<2 74
06/15/87	505	CT	P	EPI	SM	146	14 6	nd	<0 02	<1 37			
06/15/87	5081	F	A	EPI	E1	234	23 4	nd	<0 03	<1 28	nd	<0 04	<1 71
06/15/87	503	CT	A	EPI	E1	234	23 4	nd	<0 02	<0 85			
06/15/87	5085	F	A	EPI	E2	247	123 6	nd	<0 03	<0 24	nd	<0 04	<0 32
06/15/87	430	CT	A	EPI	E2	93	46 6	nd	<0 02	<0 43			
06/15/87	502	CT	A	EPI	E2	154	77 1	nd	<0 02	<0 26			
06/15/87	5082	F	P	ION	RB	159	238 5	nd	<0 03	<0 13	nd	<0 04	<0 17
06/15/87	5086	F	A	ION	CONSO	224	336 0	nd	<0 03	<0 09	nd	<0 04	<0 12
06/15/87	5073	F	A	BCKGRD	HALL	180	315 0	nd	<0 03	<0 10	nd	<0 04	<0 13
06/15/87	5074	F	A	BCKGRD	OFFICE	258	423 1	nd	<0 03	<0 07	nq	0 04	0 09
06/15/87	5075	F	A	BCKGRD	OFFICE	256	128 3	nd	<0 03	<0 23	nd	<0 04	<0 31
06/15/87	106	CT	A	BCKGRD	OFFICE	138	69 1	nd	<0 02	<0 29			
06/15/87	108	CT	A	BCKGRD	OFFICE	118	59 1	nd	<0 02	<0 34			
06/16/87	5042	F	P	LEC	BH	463	232 7		0 21	0 90	nd	<0 03	<0 13
06/16/87	225	CT	P	LEC	BH	235	118 1	nd	<0 02	<0 17			
06/16/87	217	CT	P	LEC	BH	133	66 8	nd	<0 02	<0 30			
06/16/87	237	CT	P	LEC	BH	95	47 7	nd	<0 02	<0 42			
06/16/87	5089	F	A	LEC	LOAD R	173	259 5		0 42	1 62	nd	<0 04	<0 15
06/16/87	5072	F	A	LEC	LOAD R	173	86 7	nq	0 06	0 69	nd	<0 03	<0 35
06/16/87	229	CT	A	LEC	LOAD R	173	86 7	nd	<0 02	<0 23			
06/16/87	5045	F	A	LEC	P1	386	193 8	nq	0 04	0 21	nd	<0 03	<0 15
06/16/87	230	CT	A	LEC	P1	134	67 3	nd	<0 02	<0 30			
06/16/87	226	CT	A	LEC	P1	107	53 7	nd	<0 02	<0 37			
06/16/87	224	CT	A	LEC	P1	145	72 8	nd	<0 02	<0 27			
06/16/87	5091	F	A	LEC	P3	443	776 3		0 15	0 19	nd	<0 03	<0 04
06/16/87	5090	F	A	LEC	P3	443	222 3	nq	0 04	0 18	nd	<0 03	<0 13

Table A-1 – Contiued

Date	Sample Number	Media	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det Limit	Arsenic mass (ug)	Arsenic Conc (ug/m3)	Det Limit	Gallium mass (ug)	Gallium Conc (ug/m3)
06/16/87	238	CT	A	LEC	P3	151	75 8	nd	<0 02	<0 26			
06/16/87	216	CT	A	LEC	P3	123	61 7	nd	<0 02	<0 32			
06/16/87	220	CT	A	LEC	P3	169	84 8	nd	<0 02	<0 24			
06/16/87	5077	F	A	LEC	P5	441	661 5	nq	0 09	0 14	nd	<0 04	<0 06
06/16/87	5046	F	A	LEC	P5	441	220 8	nq	0 04	0 18	nd	<0 03	<0 14
06/16/87	231	CT	A	LEC	P5	150	75 1	nd	<0 02	<0 27			
06/16/87	223	CT	A	LEC	P5	122	61 1	nd	<0 02	<0 33			
06/16/87	228	CT	A	LEC	P5	169	84 6	nd	<0 02	<0 24			
06/16/87	5078	F	A	LEC	P5CP	442	663 0	nd	<0 03	<0 05	nd	<0 03	<0 05
06/16/87	5044	F	A	LEC	P5CP	442	221 7	nd	<0 03	<0 14	nd	<0 03	<0 14
06/16/87	239	CT	A	LEC	P5CP	161	80 7	nd	<0 02	<0 25			
06/16/87	227	CT	A	LEC	P5CP	170	85 3	nd	<0 04	<0 47			
06/16/87	216	CT	A	LEC	P5CP	111	55 7	nd	<0 02	<0 36			
06/16/87	5094	F	A	LEC	P9	440	660 0	nq	0 07	0 11	nd	<0 03	<0 05
06/16/87	5092	F	A	LEC	P9	440	220 4	nq	0 03	0 14	nd	<0 03	<0 14
06/16/87	221	CT	A	LEC	P9	169	84 7	nd	<0 02	<0 24			
06/16/87	233	CT	A	LEC	P9	151	75 7	nd	<0 02	<0 26			
06/16/87	214	CT	A	LEC	P9	120	60 1	nd	<0 02	<0 33			
06/16/87	5010	F	P	GS	CM	118	81 3		0 16	2 61		0 14	2 28
06/16/87	401	CT	P	GS	CM	118	51 3	nd	<0 03	<0 49			
06/16/87	5008	F	A	GS	GS1	450	675 0		2 2	3 26		2 8	4 15
06/16/87	5002	F	A	GS	GS2	443	221 9		0 4	1 80		0 48	2 16
06/16/87	414	CT	A	GS	GS2	121	60 6	nd	<0 03	<0 50			
06/16/87	416	CT	A	GS	GS2	113	56 6	nd	<0 03	<0 53			
06/16/87	417	CT	A	GS	GS2	115	57 6	nd	<0 03	<0 52			
06/16/87	409	CT	A	GS	GS2	94	47 1	nd	<0 03	<0 64			
06/16/87	5003	F	A	GS	GS3	315	472 5	nd	<0 03	<0 06	nd	<0 03	<0 06
06/16/87	5011	F	A	GS	GS4	121	181 5		0 24	1 32		0 24	1 32
06/16/87	5101	F	P	EPI	SM	353	35 3	nd	<0 03	<0 85	nd	<0 03	<0 85
06/16/87	511	CT	P	EPI	SM	134	13 4	nd	<0 03	<2 24			
06/16/87	516	CT	P	EPI	SM	78	7 8	nd	<0 03	<3 85			
06/16/87	504	CT	P	EPI	SM	141	14 1	nd	<0 03	<2 13			
06/16/87	5112	F	A	EPI	E2	426	213 4	nd	<0 03	<0 14	nd	<0 03	<0 14
06/16/87	500	CT	A	EPI	E2	109	54 6	nd	<0 02	<0 37			
06/16/87	519	CT	A	EPI	E2	225	112 7	nd	<0 02	<0 18			
06/16/87	518	CT	A	EPI	E2	90	45 1	nd	<0 02	<0 44			
06/16/87	5107	F	A	EPI	E1	410	41 0	nd	<0 03	<0 73	nd	<0 03	<0 73
06/16/87	515	CT	A	EPI	E1	205	20 5	nd	<0 02	<0 98			
06/16/87	514	CT	A	EPI	E1	118	11 8	nd	<0 02	<1 69			
06/16/87	512	CT	A	EPI	E1	85	8 5	nd	<0 02	<2 35			
06/16/87	5109	F	A	EPI	ANNEA	137	68 7	nd	<0 03	<0 44	nd	<0 03	<0 44
06/16/87	506	CT	A	EPI	ANNEA	137	68 7	nd	<0 02	<0 29			
06/16/87	5110	F	A	ION	CONSO	375	562 5	nd	<0 03	<0 05	nd	<0 03	<0 05
06/16/87	5113	F	P	ION	RB	248	372 0	nd	<0 03	<0 08	nd	<0 03	<0 08
06/16/87	5111	F	A	BCKGRD	HALL	367	36 7	nd	<0 03	<0 82	nd	<0 03	<0 82
06/16/87	517	CT	A	BCKGRD	HALL	171	17 1	nd	<0 03	<1 75			
06/16/87	5004	F	A	BCKGRD	OFFICE	435	652 5		0 28	0 43		0 34	0 52
06/16/87	5009	F	A	BCKGRD	OFFICE	437	219 0		0 1	0 46		0 084	0 38
06/16/87	109	CT	A	BCKGRD	OFFICE	94	47 1	nd	<0 02	<0 42			
06/16/87	107	CT	A	BCKGRD	OFFICE	116	58 1	nd	<0 03	0 50			
06/16/87	105	CT	A	BCKGRD	OFFICE	112	56 1	nd	<0 03	<0 53			
06/16/87	412	CT	A	BCKGRD	OFFICE	115	57 6	nd	<0 03	<0 52			
06/16/87	5005	F	A	BCKGRD	HALL	335	502 5		0 13	0 26		0 18	0 32
06/17/87	5052	F	P	LEC	BH	475	238 2	nd	<0 03	<0 13	nd	<0 02	<0 08
06/17/87	234	CT	P	LEC	BH	164	82 2	nd	<0 04	<0 49			
06/17/87	255	CT	P	LEC	BH	154	77 2	nd	<0 04	<0 52			

Table A-1 – Contiued

Date	Sample Number	Media	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det Limit	Arsenic mass (ug)	Arsenic Conc (ug/m3)	Det Limit	Gallium mass (ug)	Gallium Conc (ug/m3)
06/17/87	248	CT	P	LEC	BH	152	76 2	nd	<0 04	<0 52			
06/17/87	5114	F	A	LEC	P1	485	727 5		0 11	0 15	nd	<0 02	<0 03
06/17/87	5048	F	A	LEC	P1	485	243 3	nd	<0 03	<0 12	nd	<0 02	<0 08
06/17/87	241	CT	A	LEC	P1	158	79 3	nd	<0 04	<0 50			
06/17/87	243	CT	A	LEC	P1	141	70 7	nd	<0 04	<0 57			
06/17/87	245	CT	A	LEC	P1	120	60 2	nd	<0 04	<0 66			
06/17/87	258	CT	A	LEC	P1	66	33 1	nd	<0 04	<1 21			
06/17/87	5050	F	A	LEC	P5	444	666 0		0 11	0 17	nd	<0 02	<0 03
06/17/87	5051	F	A	LEC	P5	444	222 4	nd	<0 03	<0 13	nd	<0 02	<0 09
06/17/87	244	CT	A	LEC	P5	278	139 3	nd	<0 04	<0 29			
06/17/87	232	CT	A	LEC	P5	152	76 2	nd	<0 04	<0 53			
06/17/87	5049	F	A	LEC	P5CP	503	754 5	nd	<0 03	<0 04	nd	<0 02	<0 03
06/17/87	5053	F	A	LEC	P5CP	503	252 4	nd	<0 03	<0 12	nd	<0 02	<0 08
06/17/87	236	CT	A	LEC	P5CP	162	81 3	nd	<0 04	<0 49			
06/17/87	247	CT	A	LEC	P5CP	157	78 8	nd	<0 04	<0 51			
06/17/87	252	CT	A	LEC	P5CP	124	62 2	nd	<0 04	<0 64			
06/17/87	259	CT	A	LEC	P5CP	60	30 1	nd	<0 04	<1 33			
06/17/87	5117	F	A	LEC	P9	481	721 5	nq	0 04	0 06	nd	<0 02	<0 03
06/17/87	5119	F	A	LEC	P9	481	241 1	nq	0 07	0 29	nq	0 02	0 08
06/17/87	242	CT	A	LEC	P9	158	79 2	nd	<0 02	<0 25			
06/17/87	246	CT	A	LEC	P9	138	69 2	nd	<0 02	<0 29			
06/17/87	249	CT	A	LEC	P9	120	60 1	nd	<0 04	<0 67			
06/17/87	257	CT	A	LEC	P9	65	32 6	nd	<0 04	<1 23			
06/17/87	5021	F	P	GS	CM	203	101 7	nq	0 1	0 98		0 16	1 57
06/17/87	410	CT	P	GS	CM	127	63 6	nd	<0 05	<0 79			
06/17/87	419	CT	P	GS	CM	76	38 1	nd	<0 05	<1 31			
06/17/87	5013	F	A	GS	GS1	436	654 0		1 1	1 68		1 9	2 91
06/17/87	5000	F	A	GS	GS2	436	226 5	nq	0 2	0 88		0 35	1 55
06/17/87	418	CT	A	GS	GS2	169	87 8	nd	<0 05	<0 57			
06/17/87	408	CT	A	GS	GS2	141	73 2	nd	<0 05	<0 68			
06/17/87	402	CT	A	GS	GS2	126	65 4	nd	<0 05	<0 76			
06/17/87	5022	F	A	GS	GS3	256	384 0	nd	<0 03	<0 08	nd	<0 02	<0 05
06/17/87	5020	F	A	GS	GS5	431	646 5		1 2	1 86		1 2	1 86
06/17/87	5030	F	P	EPI	SM	340	34 0	nd	<0 03	<0 88	nd	<0 02	<0 59
06/17/87	529	CT	P	EPI	SM	138	13 8	nd	<0 04	<2 90			
06/17/87	536	CT	P	EPI	SM	105	10 5	nd	<0 04	<3 81			
06/17/87	526	CT	P	EPI	SM	97	9 7	nd	<0 04	<4 12			
06/17/87	5025	F	A	EPI	E2	471	236 0	nd	<0 08	<0 34	nd	<0 04	<0 17
06/17/87	527	CT	A	EPI	E2	129	64 6	nd	<0 04	<0 62			
06/17/87	523	CT	A	EPI	E2	208	104 2	nd	<0 04	<0 38			
06/17/87	513	CT	A	EPI	E2	134	67 1	nd	<0 04	<0 60			
06/17/87	5026	F	A	EPI	E1	463	46 3	nd	<0 08	<1 73	nd	<0 04	<0 86
06/17/87	520	CT	A	EPI	E1	208	20 8	nd	<0 04	<1 92			
06/17/87	524	CT	A	EPI	E1	124	12 4	nd	<0 04	<3 23			
06/17/87	522	CT	A	EPI	E1	131	13 1	nd	<0 04	<3 05			
06/17/87	5034	F	A	EPI	ANNEA	284	426 0	nd	<0 08	<0 19	nd	<0 04	<0 09
06/17/87	5037	F	A	EPI	ANNEA	137	68 6	nd	<0 08	<1 17	nd	<0 04	<0 58
06/17/87	422	CT	A	EPI	ANNEA	137	68 6	nd	<0 05	<0 73			
06/17/87	5068	F	P	CLEC	AW	159	79 6		14	175 8		0 97	12 18
06/17/87	300	CT	P	CLEC	AW	159	79 6	nd	<0 02	<0 25			
06/17/87	5070	F	P	CLEC	DA	138	69 2		71	1026		25	361 31
06/17/87	302	CT	P	CLEC	DA	138	69 2		0 03	0 43			
06/17/87	5118	F	P	CLEC	GM	237	119 0		45	378		5 7	47 91
06/17/87	301	CT	P	CLEC	GM	140	70 3	nd	<0 02	<0 28			
06/17/87	307	CT	P	CLEC	GM	97	48 7	nd	<0 02	<0 41			
06/17/87	5065	F	A	CLEC	P3	168	294 0		18	61 22		2 4	8 16

Table A-1 – Contiued

Date	Sample Number	Media	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det Limit	Arsenic mass (ug)	Arsenic Conc (ug/m3)	Det Limit	Gallium mass (ug)	Gallium Conc (ug/m3)
06/17/87	5059	F	A	CLEC	P3	168	84 4		4 2	49 78		0 29	3 44
06/17/87	308	CT	A	CLEC	P3	168	84 4	nd	<0 02	<0 24			
06/17/87	5116	F	A	CLEC	P5	248	124 4		6 3	50 62		0 43	3 46
06/17/87	5061	F	A	CLEC	P5	246	369 0		25	67 75	nq	0 2	0 54
06/17/87	309	CT	A	CLEC	P5	248	124 4	nd	<0 02	<0 16			
06/17/87	5058	F	A	CLEC	P5CP	246	369 0	nq	0 03	0 08	nd	<0 03	<0 08
06/17/87	5067	F	A	CLEC	P5CP	246	123 1	nd	<0 03	<0 24	nd	<0 03	<0 24
06/17/87	303	CT	A	CLEC	P5CP	246	123 1	nd	<0 02	<0 16			
06/17/87	5057	F	A	CLEC	P7	146	73 3		1 9	25 91		0 11	1 50
06/17/87	305	CT	A	CLEC	P7	146	73 3	nd	<0 02	<0 27			
06/17/87	5060	F	A	CLEC	P7CP	131	65 6	nd	<0 03	<0 46	nd	<0 03	<0 46
06/17/87	5056	F	A	CLEC	P7CP	131	196 5	nd	<0 03	<0 15	nd	<0 03	<0 15
06/17/87	306	CT	A	CLEC	P7CP	131	65 6	nd	<0 02	<0 30			
06/17/87	5066	F	A	CLEC	BCKGR	253	379 5	nd	<0 1	<0 26	nd	<0 2	<0 53
06/17/87	5055	F	A	CLEC	BCKGR	145	217 5	nd	<0 03	<0 14	nd	<0 03	<0 14
06/17/87	5028	F	P	ION	RB	235	352 5	nd	<0 08	<0 23	nd	<0 04	<0 11
06/17/87	5035	F	A	ION	CONSO	307	460 5	nd	<0 08	<0 17	nd	<0 04	<0 09
06/17/87	5014	F	A	BCKGRD	HALL	414	621 0	nd	<0 08	<0 13	nq	0 1	0 16
06/17/87	5001	F	A	BCKGRD	OFFICE	453	226 9	nd	<0 08	<0 35	nd	<0 04	<0 18
06/17/87	5006	F	A	BCKGRD	OFFICE	453	679 5	nd	<0 08	<0 12	nq	0 08	0 12
06/17/87	104	CT	A	BCKGRD	OFFICE	165	82 6	nd	<0 05	<0 61			
06/17/87	116	CT	A	BCKGRD	OFFICE	146	73 1	nd	<0 05	<0 68			
06/17/87	100	CT	A	BCKGRD	OFFICE	142	71 1	nd	<0 05	<0 70			
06/18/87	5139	F	P	LEC	BH	463	232 0		0 44	1 90		0 56	2 41
06/18/87	256	CT	P	LEC	BH	172	86 2		0 06	0 66			
06/18/87	262	CT	P	LEC	BH	154	77 2	nd	<0 04	<0 52			
06/16/87	278	CT	P	LEC	BH	137	68 6	nd	<0 02	<0 28			
06/12/87	5120	F	P	LEC	KO	435	218 6	nd	<0 08	<0 37	nd	<0 04	<0 18
06/12/87	273	CT	P	LEC	KO	180	90 5	nd	<0 02	<0 22			
06/18/87	270	CT	P	LEC	KO	143	71 9		0 15	2 09			
06/18/87	263	CT	P	LEC	KO	112	56 3	nd	<0 02	<0 36			
06/18/87	5054	F	A	LEC	LOAD R	179	268 5	nq	0 2	0 74	nd	<0 04	<0 15
06/12/87	5122	F	A	LEC	LOAD R	179	89 7	nd	<0 08	<0 89	nd	<0 04	<0 45
06/16/87	274	CT	A	LEC	LOAD R	179	89 7	nd	<0 02	<0 22			
06/18/87	5131	F	A	LEC	P3	405	607 5		0 42	0 69	nq	0 4	0 66
06/18/87	5133	F	A	LEC	P3	405	203 2	nd	<0 08	<0 39	nd	<0 04	<0 20
06/16/87	275	CT	A	LEC	P3	143	71 7	nd	<0 03	<0 42			
06/18/87	267	CT	A	LEC	P3	140	70 2	nd	<0 03	<0 43			
06/18/87	271	CT	A	LEC	P3	122	61 2	nd	<0 03	<0 49			
06/12/87	5128	F	A	LEC	P6	444	666 0	nq	0 2	0 30	nd	<0 04	<0 06
06/18/87	5132	F	A	LEC	P6	444	222 3	nd	<0 1	<0 45	nd	<0 2	<0 90
06/16/87	272	CT	A	LEC	P6	162	81 1	nq	0 1	1 23			
06/16/87	265	CT	A	LEC	P5	141	70 6	nd	<0 04	<0 57			
06/16/87	279	CT	A	LEC	P5	141	70 6	nd	<0 04	<0 57			
06/16/87	5138	F	A	LEC	P5CP	439	658 5	nd	<0 08	<0 12	nd	<0 04	<0 06
06/18/87	5121	F	A	LEC	P5CP	439	219 9	nd	<0 08	<0 36	nd	<0 04	<0 18
06/16/87	276	CT	A	LEC	P5CP	160	80 2	nd	<0 02	<0 25			
06/18/87	269	CT	A	LEC	P5CP	149	74 6	nd	<0 02	<0 27			
06/18/87	261	CT	A	LEC	P5CP	130	65 1	nd	<0 02	<0 31			
06/12/87	5127	F	A	LEC	P7	443	664 5	nd	<0 08	<0 12	nd	<0 04	<0 06
06/18/87	5129	F	A	LEC	P7	443	222 3	nd	<0 08	<0 36	nd	<0 04	<0 18
06/18/87	277	CT	A	LEC	P7	162	81 3	nd	<0 03	<0 37			
06/18/87	268	CT	A	LEC	P7	141	70 7	nd	<0 03	<0 42			
06/16/87	266	CT	A	LEC	P7	140	70 2	nd	<0 02	<0 28			
06/16/87	5017	F	A	GS	GS1	371	608 4		2 9	4 77		3 1	5 09
06/18/87	5141	F	A	GS	GS2	450	225 4		0 34	1 51		0 36	1 60

Table A-1 – Contiued

Date	Sample Number	Media	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det Limit	Arsenic mass (ug)	Arsenic Conc (ug/m3)	Det Limit	Gallium mass (ug)	Gallium Conc (ug/m3)
06/18/87	114	CT	A	GS	GS2	135	67 6	nd	<0 03	<0 44			
06/18/87	413	CT	A	GS	GS2	167	83 7	nd	<0 03	<0 36			
06/18/87	415	CT	A	GS	GS2	148	74 1	nd	<0 03	<0 40			
06/18/87	5135	F	A	GS	GS5	300	525 0		3 7	7 05		3 9	7 43
06/18/87	5024	F	P	EPI	SM	356	35 6	nd	<0 03	<0 84	nd	<0 02	<0 56
06/18/87	534	CT	P	EPI	SM	120	12 0	nd	<0 05	<4 17			
06/18/87	532	CT	P	EPI	SM	96	9 6	nd	<0 05	<5 21			
06/18/87	420	CT	P	EPI	SM	140	14 0	nd	<0 05	<3 57			
06/18/87	5029	F	A	EPI	E2	454	227 5	nd	<0 03	<0 13	nd	<0 02	<0 09
06/18/87	429	CT	A	EPI	E2	190	95 2	nd	<0 04	<0 42			
06/18/87	426	CT	A	EPI	E2	141	70 8	nd	<0 04	<0 57			
06/18/87	425	CT	A	EPI	E2	123	61 6	nd	<0 03	<0 49			
06/18/87	5031	F	A	EPI	E1	452	45 2	nd	<0 03	<0 66	nd	<0 02	<0 44
06/18/87	531	CT	A	EPI	E1	122	12 2	nd	<0 04	<3 28			
06/18/87	507	CT	A	EPI	E1	199	19 9	nd	<0 04	<2 01			
06/18/87	423	CT	A	EPI	E1	131	13 1	nd	<0 04	<3 05			
06/18/87	5039	F	A	EPI	ANNEA	373	186 7	nd	<0 03	<0 16	nd	<0 02	<0 11
06/18/87	424	CT	A	EPI	ANNEA	125	62 6	nd	<0 04	<0 64			
06/18/87	530	CT	A	EPI	ANNEA	109	54 6	nd	<0 04	<0 73			
06/18/87	421	CT	A	EPI	ANNEA	139	69 6	nd	<0 04	<0 57			
06/18/87	5151	F	P	CLEC	AW	175	87 8		11	125 3		0 87	9 91
06/18/87	320	CT	P	CLEC	AW	175	87 8	nd	<0 04	<0 46			
06/18/87	5138	F	A	CLEC	P1	180	270 0		27	100 0		4 8	17 78
06/18/87	5153	F	A	CLEC	P1	180	93 5		10	107 0		1 2	12 84
06/18/87	313	CT	A	CLEC	P1	180	93 5	nd	<0 04	<0 43			
06/18/87	5152	F	A	CLEC	P1CP	228	342 0	nd	<0 1	<0 29	nd	<0 2	<0 58
06/18/87	5125	F	A	CLEC	P1CP	228	114 2	nd	<0 1	<0 88	nd	<0 2	<1 75
06/18/87	310	CT	A	CLEC	P1CP	228	114 2	nd	<0 04	<0 35			
06/18/87	5124	F	A	CLEC	BCKGR	234	351 0	nd	<0 1	<0 28	nd	<0 2	<0 57
06/18/87	5040	F	P	ION	RB	286	429 0	nd	<0 03	<0 07	nd	<0 02	<0 05
06/18/87	5036	F	A	ION	CONSO	453	679 5	nd	<0 03	<0 04	nd	<0 02	<0 03
06/18/87	5038	F	A	BCKGRD	HALL	455	45 5	nd	<0 03	<0 66	nd	<0 02	<0 44
06/18/87	428	CT	A	BCKGRD	HALL	193	19 3	nd	<0 04	<2 07			
06/18/87	508	CT	A	BCKGRD	HALL	138	13 8	nd	<0 04	<2 90			
06/18/87	535	CT	A	BCKGRD	HALL	124	12 4	nd	<0 04	<3 23			
06/18/87	5123	F	A	BCKGRD	OFFICE	444	222 4	nq	0 08	0 36	nq	0 1	0 45
06/18/87	119	CT	A	BCKGRD	OFFICE	137	68 6	nd	<0 03	<0 44			
06/18/87	110	CT	A	BCKGRD	OFFICE	163	81 6	nd	<0 03	<0 37			
06/18/87	102	CT	A	BCKGRD	OFFICE	144	72 1	nd	<0 03	<0 42			
06/18/87	5134	F	A	BCKGRD	OFFICE	450	675 0		0 3	0 44		0 31	0 46
06/18/87	5142	F	A	BCKGRD	HALL	246	369 0	nd	<0 08	<0 22	nq	0 08	0 22

Table A-2. Combined Filter and Charcoal Tube Arsenic Results

Date	Sample Number	Time (min)	Volume (liters)	Type	Room	Person/ Location	Arsenic mass (ug) FILTER	Arsenic mass (ug) TUBE #1	Arsenic mass (ug) TUBE #2	Arsenic mass (ug) TUBE #3	Arsenic mass (ug) SUM	Arsenic Conc (ug/m3)	Tube/ Sum Ratio
06/15/87	5103	288	144	P	LEC	BH	0 03	<0 04			0 03	0 21	
06/15/87	5099	309	155	A	LEC	P3	<0 03	<0 04	<0 04	<0 04	<0 07	<0 45	
06/15/87	5096	317	159	A	LEC	P5	0 04	<0 04	<0 04	<0 04	0 04	0 25	
06/15/87	5102	304	152	A	LEC	P5CP	<0 03	<0 04	<0 02	<0 02	<0 06	<0 38	
06/15/87	5097	315	158	A	LEC	P9	0 04	<0 04	<0 04		0 04	0 25	
06/15/87	5088	145	73	P	GS	DD	0 09	<0 02			0 09	1 24	
06/15/87	5084	237	119	A	GS	GS2	<0 03	<0 02	<0 02		<0 05	<0 42	
06/15/87	5085	247	124	A	EPI	E2	<0 03	<0 02	<0 02		<0 05	<0 40	
06/15/87	5075	256	128	A	BCKGRD	OFFICE	<0 03	<0 02	<0 02		<0 05	<0 39	
06/16/87	5042	463	233	P	LEC	BH	0 21	<0 02	<0 02		0 21	0 90	
06/16/87	5072	173	87	A	LEC	LOAD R	0 06	<0 02			0 06	0 69	
06/16/87	5045	386	194	A	LEC	P1	0 04	<0 02	<0 02	<0 02	0 04	0 21	
06/16/87	5090	443	222	A	LEC	P3	0 04	<0 02	<0 02	<0 02	0 04	0 18	
06/16/87	5046	441	221	A	LEC	P5	0 04	<0 02	<0 02	<0 02	0 04	0 18	
06/16/87	5044	442	222	A	LEC	P5CP	<0 03	<0 02	<0 04	<0 02	<0 06	<0 27	
06/16/87	5092	440	220	A	LEC	P9	0 03	<0 02	<0 02	<0 02	0 03	0 14	
06/16/87	5010	118	61	P	GS	CM	0 16	<0 03			0 16	2 61	
06/16/87	5002	443	222	A	GS	GS2	0 4	<0 03	<0 03	<0 06	0 4	1 80	
06/16/87	5109	137	69	A	EPI	ANNEAL	<0 03	<0 02			<0 05	<0 73	
06/16/87	5112	426	213	A	EPI	E2	<0 03	<0 02	<0 02	<0 02	<0 05	<0 23	
06/16/87	5009	437	219	A	BCKGRD	OFFICE	0 1	<0 03	<0 03	<0 05	0 1	0 46	
06/17/87	5052	475	238	P	LEC	BH	<0 03	<0 04	<0 04	<0 08	<0 08	<0 35	
06/17/87	5048	485	243	A	LEC	P1	<0 03	<0 04	<0 04	<0 08	<0 08	<0 34	
06/17/87	5051	444	222	A	LEC	P5	<0 03	<0 04	<0 04		<0 07	<0 31	
06/17/87	5053	503	252	A	LEC	P5CP	<0 03	<0 04	<0 04	<0 08	<0 08	<0 33	
06/17/87	5119	481	241	A	LEC	P9	0 07	<0 02	<0 02	<0 08	0 07	0 29	
06/17/87	5021	203	102	P	GS	CM	0 1	<0 05	<0 05		0 10	0 98	
06/17/87	5000	436	226	A	GS	GS2	0 2	<0 05	<0 05	<0 05	0 20	0 88	
06/17/87	5037	137	69	A	EPI	ANNEAL	<0 08	<0 05			<0 13	<1 89	
06/17/87	5025	471	236	A	EPI	E2	<0 08	<0 04	<0 04	<0 04	<0 12	<0 51	
06/17/87	5068	159	80	P	CLEC	AW	14	<0 02			14 00	176	
06/17/87	5070	138	69	P	CLEC	DA	71	0 03			71 03	1027	<0 001
06/17/87	5118	237	119	P	CLEC	GM	45	<0 02	<0 02		45 00	378	
06/17/87	5059	168	84	A	CLEC	P3	4 2	<0 02			4 20	49 8	
06/17/87	5116	248	124	A	CLEC	P5	6 3	<0 02			6 30	50 6	

Table A-2 - Continued

Date	Sample Number	Time (min)	Volume (liters)	Type	Room	Person/ Location	Arsenic mass (ug) FILTER	Arsenic mass (ug) TUBE #1	Arsenic mass (ug) TUBE #2	Arsenic mass (ug) TUBE #3	Arsenic mass (ug) SUM	Arsenic Conc (ug/m3)	Tube/ Sum Ratio
06/17/87	5067	246	123	A	CLEC	P5CP	<0 03	<0 02			<0 05	<0 41	
06/17/87	5057	146	73	A	CLEC	P7	1 9	<0 02			1 90	25 9	
06/17/87	5060	131	66	A	CLEC	P7CP	<0 03	<0 02			<0 05	<0 76	
06/17/87	5001	453	227	A	BCKGRD	OFFICE	<0 08	<0 05	<0 05	<0 05	<0 13	<0 57	
06/18/87	5139	463	232	P	LEC	BH	0 44	0 057	<0 02	<0 04	0 50	2 14	0 115
06/18/87	5120	435	219	P	LEC	KO	<0 08	0 15	<0 02	<0 02	0 15	0 69	
06/18/87	5122	179	90	A	LEC	LOAD R	<0 08	<0 02			<0 10	<1 11	
06/18/87	5133	405	203	A	LEC	P3	<0 08	<0 03	<0 03	<0 03	<0 11	<0 54	
06/18/87	5132	444	222	A	LEC	P5	<0 1	0 1	<0 04	<0 04	0 10	0 45	
06/18/87	5121	439	220	A	LEC	P5CP	<0 08	<0 02	<0 02	<0 02	<0 10	<0 45	
06/18/87	5126	443	222	A	LEC	P7	<0 08	<0 03	<0 03	<0 02	<0 11	<0 48	
06/18/87	5141	450	225	A	GS	GS2	0 34	<0 03	<0 03	<0 03	0 34	1 51	
06/18/87	5039	373	187	A	EPI	ANNEAL	<0 03	<0 04	<0 04	<0 04	<0 07	<0 37	
06/18/87	5029	454	227	A	EPI	E2	<0 03	<0 04	<0 04	<0 03	<0 07	<0 29	
06/18/87	5151	175	88	P	CLEC	AW	11	<0 04			11	125	
06/18/87	5153	180	93	A	CLEC	P1	10	<0 04			10	107	
06/18/87	5125	228	114	A	CLEC	P1CP	<0 1	<0 04			<0 14	<1 23	
06/18/87	5123	444	222	A	BCKGRD	OFFICE	0 08	<0 03	<0 03	<0 03	0 08	0 36	
06/15/87	5080	146	14 6	P	EPI	SM	<0 03	<0 02			<0 05	<3 42	
06/15/87	5081	234	23 4	A	EPI	E1	<0 03	<0 02			<0 05	<2 14	
06/16/87	5101	353	35 3	P	EPI	SM	<0 03	<0 03	<0 03	<0 03	<0 06	<1 70	
06/16/87	5107	410	41 0	A	EPI	E1	<0 03	<0 02	<0 02	<0 02	<0 05	<1 22	
06/16/87	5111	367	36 7	A	BCKGRD	EPI	<0 03	<0 03			<0 06	<1 63	
06/17/87	5030	340	34 0	P	EPI	SM	<0 03	<0 04	<0 04	<0 04	<0 07	<2 06	
06/17/87	5026	463	46 3	A	EPI	E1	<0 08	<0 04	<0 04	<0 04	<0 12	<2 59	
06/18/87	5038	455	45 5	A	BCKGRD	EPI	<0 03	<0 04	<0 04	<0 04	<0 07	<1 54	
06/18/87	5024	356	35 6	P	EPI	SM	<0 03	<0 05	<0 05	<0 05	<0 08	<2 25	
06/18/87	5031	452	45 2	A	EPI	E1	<0 03	<0 04	<0 04	<0 04	<0 07	<1 55	

Table A-3 Filter Only Arsenic and Gallium Results

Date	Sample Number	Type	Room	Person/ Location	Time (min)	Volume (liters)	Det Limit	Arsenic mass (ug)	Arsenic Conc (ug/m3)	Det Limit	Gallium mass (ug)	Gallium Conc (ug/m3)	Ratio Gallium/ Arsenic
06/15/87	5103	P	LEC	BH	108	54 2				nd	<0 04	<0 74	
06/15/87	5104	A	LEC	P3	309	463 5		0 11	0 24	nd	<0 04	<0 09	
06/15/87	5099	A	LEC	P3	309	155 3				nd	<0 04	<0 26	
06/15/87	5096	A	LEC	P5	317	159 0				nd	<0 04	<0 25	
06/15/87	5105	A	LEC	P5	317	475 5		0 12	0 25	nd	<0 04	<0 08	
06/15/87	5098	A	LEC	P5CP	304	456 0	nd	<0 03	<0 07	nd	<0 04	<0 09	
06/15/87	5102	A	LEC	P5CP	304	152 2				nd	<0 04	<0 26	
06/15/87	5100	A	LEC	P9	315	472 5	nq	0 03	0 06	nd	<0 04	<0 08	
06/15/87	5097	A	LEC	P9	315	158 0	nq				0 04	0 25	
06/15/87	5087	P	GS	CM	141	211 5		0 92	4 35		0 93	4 40	1 01
06/15/87	5088	P	GS	DD	145	72 7					0 13	1 79	
06/15/87	5076	A	GS	GS1	235	352 5		0 22	0 62		0 34	0 96	1 55
06/15/87	5084	A	GS	GS2	237	118 7				nq	0 06	0 51	
06/15/87	5079	A	GS	GS3	240	360 0	nd	<0 03	<0 08	nd	<0 04	<0 11	
06/15/87	5080	P	EPI	SM	146	14 6				nd	<0 04	<2 74	
06/15/87	5081	A	EPI	E1	234	23 4				nd	<0 04	<1 71	
06/15/87	5085	A	EPI	E2	247	123 6				nd	<0 04	<0 32	
06/15/87	5082	P	ION	RB	159	238 5	nd	<0 03	<0 13	nd	<0 04	<0 17	
06/15/87	5086	A	ION	CONSOL	224	336 0	nd	<0 03	<0 09	nd	<0 04	<0 12	
06/15/87	5073	A	BCKGRD	HALL	180	315 0	nd	<0 03	<0 10	nd	<0 04	<0 13	
06/15/87	5075	A	BCKGRD	OFFICE	256	128 3				nd	<0 04	<0 31	
06/15/87	5074	A	BCKGRD	OFFICE	258	423 1	nd	<0 03	<0 07	nq	0 04	0 09	
06/16/87	5042	P	LEC	BH	463	232 7				nd	<0 03	<0 13	
06/16/87	5072	A	LEC	LOAD R	173	86 7				nd	<0 03	<0 35	
06/16/87	5089	A	LEC	LOAD R	173	259 5		0 42	1 62	nd	<0 04	<0 15	
06/16/87	5045	A	LEC	P1	386	193 8				nd	<0 03	<0 15	
06/16/87	5090	A	LEC	P3	443	222 3				nd	<0 03	<0 13	
06/16/87	5091	A	LEC	P3	443	775 3		0 15	0 19	nd	<0 03	<0 04	
06/16/87	5046	A	LEC	P5	441	220 8				nd	<0 03	<0 14	
06/16/87	5077	A	LEC	P5	441	661 5	nq	0 09	0 14	nd	<0 04	<0 06	
06/16/87	5078	A	LEC	P5CP	442	663 0	nd	<0 03	<0 05	nd	<0 03	<0 05	
06/16/87	5044	A	LEC	P5CP	442	221 7				nd	<0 03	<0 14	
06/16/87	5094	A	LEC	P9	440	660 0	nq	0 07	0 11	nd	<0 03	<0 05	

Table A-3 - Continued

Date	Sample Number	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det. Limit	Arsenic mass (ug)	Arsenic Conc. (ug/m3)	Det. Limit	Gallium mass (ug)	Gallium Conc (ug/m3)	Ratio Gallium/ Arsenic
06/16/87	5092	A	LEC	P9	440	220 4				nd	<0 03	<0 14	
06/16/87	5010	P	GS	CM	118	61 3					0 14	2 28	0 88
06/16/87	5008	A	GS	GS1	450	675 0		2 2	3 26		2 8	4 15	1 27
06/16/87	5002	A	GS	GS2	443	221 9					0 48	2 16	1 20
06/16/87	5003	A	GS	GS3	315	472 5	nd	<0 03	<0 06	nd	<0 03	<0 06	
06/16/87	5011	A	GS	GS4	121	181 5		0 24	1 32		0 24	1 32	1 00
06/16/87	5101	P	EPI	SM	353	35 3				nd	<0 03	<0 85	
06/16/87	5109	A	EPI	ANNEAL	137	68 7				nd	<0 03	<0 44	
06/16/87	5107	A	EPI	E1	410	41 0				nd	<0 03	<0 73	
06/16/87	5112	A	EPI	E2	426	213 4				nd	<0 03	<0 14	
06/16/87	5113	P	ION	RB	248	372 0	nd	<0 03	<0 08	nd	<0 03	<0 08	
06/16/87	5110	A	ION	CONSOL	375	562 5	nd	<0 03	<0 05	nd	<0 03	<0 05	
06/16/87	5111	A	BCKGRD	HALL	367	36 7				nd	<0 03	<0 82	
06/16/87	5005	A	BCKGRD	HALL	335	502 5		0 13	0 26		0 16	0 32	1 23
06/16/87	5009	A	BCKGRD	OFFICE	437	219 0					0 08	0 38	0 84
06/16/87	5004	A	BCKGRD	OFFICE	435	652 5		0 28	0 43		0 34	0 52	1 21
06/17/87	5052	P	LEC	BH	475	238 2				nd	<0 02	<0 08	
06/17/87	5114	A	LEC	P1	485	727 5		0 11	0 15	nd	<0 02	<0 03	
06/17/87	5048	A	LEC	P1	485	243 3				nd	<0 02	<0 08	
06/17/87	5051	A	LEC	P5	444	222 4				nd	<0 02	<0 09	
06/17/87	5050	A	LEC	P5	444	666 0		0 11	0 17	nd	<0 02	<0 03	
06/17/87	5049	A	LEC	P5CP	503	754 5	nd	<0 03	<0 04	nd	<0 02	<0 03	
06/17/87	5053	A	LEC	P5CP	503	252 4				nd	<0 02	<0 08	
06/17/87	5119	A	LEC	P9	481	241 1				nq	0 02	0 08	
06/17/87	5117	A	LEC	P9	481	721 5	nq	0 04	0 06	nd	<0 02	<0 03	
06/17/87	5068	P	CLEC	AW	159	79 6					0 97	12 18	0 07
06/17/87	5070	P	CLEC	DA	138	69 2					25	361 31	0 35
06/17/87	5118	P	CLEC	GM	237	119 0					5 7	47 91	0 13
06/17/87	5059	A	CLEC	P3	168	84 4					0 29	3 44	0 07
06/17/87	5065	A	CLEC	P3	168	294 0		18	61 22		2 4	8 16	0 13
06/17/87	5061	A	CLEC	P5	246	369 0		25	67 75	nq	0 2	0 54	
06/17/87	5116	A	CLEC	P5	248	124 4					0 43	3 46	0 07
06/17/87	5067	A	CLEC	P5CP	246	123 1				nd	<0 03	<0 24	

Table A-3 - Continued

Date	Sample Number	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det. Limit	Arsenic mass (ug)	Arsenic Conc. (ug/m3)	Det. Limit	Gallium mass (ug)	Gallium Conc (ug/m3)	Ratio Gallium/ Arsenic
06/17/87	5058	A	CLEC	P5CP	246	369 0	nq	0 03	0 08	nd	<0 03	<0 08	
06/17/87	5057	A	CLEC	P7	146	73 3					0 11	1 50	0 06
06/17/87	5056	A	CLEC	P7CP	131	196 5	nd	<0 03	<0 15	nd	<0 03	<0 15	
06/17/87	5060	A	CLEC	P7CP	131	65 6				nd	<0 03	<0 46	
06/17/87	5021	P	GS	CM	203	101 7					0 16	1 57	
06/17/87	5013	A	GS	GS1	436	654 0		1 1	1 68		1 9	2 91	1 73
06/17/87	5000	A	GS	GS2	436	226 5					0 35	1 55	
06/17/87	5022	A	GS	GS3	256	384 0	nd	<0 03	<0 08	nd	<0 02	<0 05	
06/17/87	5020	A	GS	GS5	431	646 5		1 2	1 86		1 2	1 86	1 00
06/17/87	5030	P	EPI	SM	340	34 0				nd	<0 02	<0 59	
06/17/87	5034	A	EPI	ANNEAL	284	426 0	nd	<0 08	<0 19	nd	<0 04	<0 09	
06/17/87	5037	A	EPI	ANNEAL	137	68 6				nd	<0 04	<0 58	
06/17/87	5026	A	EPI	E1	463	46 3				nd	<0 04	<0 86	
06/17/87	5025	A	EPI	E2	471	236 0				nd	<0 04	<0 17	
06/17/87	5028	P	ION	RB	235	352 5	nd	<0 08	<0 23	nd	<0 04	<0 11	
06/17/87	5035	A	ION	CONSOL	307	460 5	nd	<0 08	<0 17	nd	<0 04	<0 09	
06/17/87	5055	A	BCKGRD	HALL	145	217 5	nd	<0 03	<0 14	nd	<0 03	<0 14	
06/17/87	5066	A	BCKGRD	HALL	253	379 5	nd	<0 1	<0 26	nd	<0 2	<0 53	
06/17/87	5014	A	BCKGRD	HALL	414	621 0	nd	<0 08	<0 13	nq	0 1	0 16	
06/17/87	5006	A	BCKGRD	OFFICE	453	679 5	nd	<0 08	<0 12	nq	0 08	0 12	
06/17/87	5001	A	BCKGRD	OFFICE	453	226 9				nd	<0 04	<0 18	
06/18/87	5139	P	LEC	BH	463	232 0					0 56	2 41	1 27
06/18/87	5120	P	LEC	KO	435	218 6				nd	<0 04	<0 18	
06/18/87	5054	A	LEC	LOAD R	179	268 5	nq	0 2	0 74	nd	<0 04	<0 15	
06/18/87	5122	A	LEC	LOAD R	179	89 7				nd	<0 04	<0 45	
06/18/87	5133	A	LEC	P3	405	203 2				nd	<0 04	<0 20	
06/18/87	5131	A	LEC	P3	405	607 5		0 42	0 69	nq	0 4	0 66	0 95
06/18/87	5132	A	LEC	P5	444	222 3				nd	<0 20	<0 90	
06/18/87	5128	A	LEC	P5	444	666 0	nq	0 2	0 30	nd	<0 04	<0 06	
06/18/87	5121	A	LEC	P5CP	439	219 9				nd	<0 04	<0 18	
06/18/87	5138	A	LEC	P5CP	439	658 5	nd	<0 08	<0 12	nd	<0 04	<0 06	
06/18/87	5127	A	LEC	P7	443	664 5	nd	<0 08	<0 12	nd	<0 04	<0 06	
06/18/87	5126	A	LEC	P7	443	222 3				nd	<0 04	<0 18	

Table A-3 - Continued

Date	Sample Number	Type	Room	Person/ Loca-tion	Time (min)	Volume (liters)	Det. Limit	Arsenic mass (ug)	Arsenic Conc. (ug/m3)	Det. Limit	Gallium mass (ug)	Gallium Conc (ug/m3)	Ratio Gallium/ Arsenic
06/18/87	5151	P	CLEC	AW	175	87 8					0 87	9 91	0 08
06/18/87	5136	A	CLEC	P1	180	270 0		27	100 00		4 8	17 78	0 18
06/18/87	5153	A	CLEC	P1	180	93 5					1 2	12 84	0 12
06/18/87	5125	A	CLEC	P1CP	228	114 2				nd	<0 2	<1 75	
06/18/87	5152	A	CLEC	P1CP	228	342 0	nd	<0 1	<0 29	nd	<0 2	<0 58	
06/18/87	5017	A	GS	GS1	371	608 4		2 9	4 77		3 1	5 09	1 07
06/18/87	5141	A	GS	GS2	450	225 4					0 36	1 60	1 06
06/18/87	5135	A	GS	GS5	300	525 0		3 7	7 05		3 9	7 43	1 05
06/18/87	5024	P	EPI	SM	356	35 6				nd	<0 02	<0 56	
06/18/87	5031	A	EPI	E1	452	45 2				nd	<0 02	<0 44	
06/18/87	5029	A	EPI	E2	454	227 5				nd	<0 02	<0 09	
06/18/87	5039	A	EPI	ANNEAL	373	186 7				nd	<0 02	<0 11	
06/18/87	5040	P	ION	RB	286	429 0	nd	<0 03	<0 07	nd	<0 02	<0 05	
06/18/87	5036	A	ION	CONSOL	453	679 5	nd	<0 03	<0 04	nd	<0 02	<0 03	
06/18/87	5038	A	BCKGRD	HALL	455	45 5				nd	<0 02	<0 44	
06/18/87	5124	A	BCKGRD	HALL	234	351 0	nd	<0 1	<0 28	nd	<0 20	<0 57	
06/18/87	5142	A	BCKGRD	HALL	246	369 0	nd	<0 08	<0 22	nq	0 08	0 22	
06/18/87	5123	A	BCKGRD	OFFICE	444	222 4				nq	0 1	0 45	
06/18/87	5134	A	BCKGRD	OFFICE	450	675 0		0 3	0 44		0 31	0 46	1 03

Table A-4 Acid Sample Results

Date	Sample Number	Media	Type	Room	Time (min)	Volume (liters)	HCL mass (ug)	HCL Conc (ug/m3)	Nitric mass (ug)	Nitric Conc. (ug/m3)
06/15/87	810	AT	A	LEC	128	64	5	78	0 8	13
06/15/87	813	AT	A	LEC	206	103	5	49	<0 5	<5
06/15/87	803	AT	A	EPI	235	118	<1	<9	<0 5	<4
06/16/87	811	AT	A	LEC	212	106	15	142	4 3	41
06/16/87	812	AT	A	LEC	243	121	1520	12600	839	6920
06/16/87	824	AT	A	EPI	196	98	2	20	<0 5	<5
06/16/87	820	AT	A	EPI	200	100	1	10	<0 5	<5
06/17/87	802	AT	A	LEC	155	78	3	39	<0 5	<6
06/17/87	801	AT	A	LEC	311	156	7 3	47	1 6	10
06/17/87	823	AT	A	EPI	245	122	<1	<8	<0 5	<4
06/17/87	821	AT	A	EPI	212	106	<1	<9	<0 5	<5
06/18/87	819	AT	A	LEC	260	130	131	1008	22	169
06/18/87	815	AT	A	LEC	134	67	18	269	3 3	49
06/18/87	825	AT	A	EPI	241	120	3	25	<0 5	<4
06/18/87	828	AT	A	EPI	192	96	<1	<10	<0 5	<5
06/15/87	814	AT		Blank		0	5		<0 5	
06/16/87	800	AT		Blank		0	5		<0 5	
06/17/87	804	AT		Blank		0	5		<0 5	
06/17/87	822	AT		Blank		0	6		<0 5	
06/18/87	829	AT		Blank		0	2		<0 5	
06/18/87	816	AT		Blank		0	7		<0 5	