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P R E - P U B L I C A T I O N

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# CONTROL OF STYRENE VAPOR DURING THE MANUFACTURE OF FIBER-REINFORCED PLASTICS SMALL PARTS

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FINAL REPORT

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## ABSTRACT

A series of 7 fiber-reinforced plastics (FRP) plant surveys provided information for this evaluation of control technology for styrene vapor in fiber reinforced polyester/styrene resin lamination of small parts. The field surveys were conducted in plants that make small items such as accessory boat parts, bathroom fixtures and other assorted small items. Two in-depth surveys were conducted in plants selected on the basis of having designed and constructed special ventilation systems for the control of styrene vapor in the workplace. A total of 142 personal and area samples for styrene vapor taken in the survey of these two plants provide data for this report. These data were evaluated to determine the average styrene exposure of workers performing different tasks in the plants. One set of personal samples was obtained while the working habits of each employee sampled were observed and noted on a checklist of good and bad work practices. This data was analyzed to obtain a series of linear regression analyses which provide a measurement of the relative effectiveness of different work practices.

The results of this study should be useful to owners of plants manufacturing small items with FRP for designing control systems able to meet the current OSHA PEL of 100 ppm styrene and probably to meet the NIOSH recommended 8-hour TWA of 50 ppm.

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ACKNOWLEDGMENT

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# I. INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) has the responsibility for conducting research and developing criteria for the advancement of health and safety in the workplace. To meet the need for attaining lower levels of toxic materials in the workplace, NIOSH has conducted a series of industry-wide control technology evaluations. The goal of these evaluations is to provide industry with documented successful control systems. In carrying out these evaluations, NIOSH seeks to identify the best available control techniques practiced by selected companies, to encourage the distribution of this knowledge within the industrial community, and to outline control technology research needs. This is provided as a service to those companies wishing to improve the quality of the workplace environment and to those industries needing to meet more stringent control levels in the workplace.

Since 1976, the Engineering Control Technology Branch (ECTB) of DPSE, NIOSH has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial processes, and specific control techniques. Examples of these completed studies include: the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate control techniques in the industry that meet the OSHA PEL of 100 ppm styrene and also the NIOSH recommended 8-hour TWA of 50 ppm.

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. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds 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 study was performed to collect information on the effective controls for styrene vapor in small parts manufacture in the fiber-reinforced plastics (FRP) industry. Two of the seven plants evaluated in preliminary surveys were selected which had the best engineering controls. In-depth studies were made of these plants to determine the level of control and the detailed performance of the control system. Work practices, monitoring, and the use of personal protective equipment by plant personnel were observed. These two surveys represent plants that use polyester styrene resin and produce small items by laminating fiberglass roving. The comparison stops there because each plant makes a different product with different production methods.

## II. POTENTIAL HAZARDS

A review of the health literature for this and other FRP industries indicates that the major health problems include: irritation to the mucous membranes; solvent narcosis from exposure to styrene vapor; and contact dermatitis from skin contact with solvents, fiberglass, and uncured polyester resin.[1,2] Changes in psychromotor test results were noted among subjects in styrene exposed workers at both high (82 $\pm$ 44 ppm) and low (9 $\pm$ 15 ppm) styrene concentrations, whereas eye and mucous membrane irritations were shown to be more frequent in individuals exposed to the higher range of concentrations.[3]

Styrene, because of its volatility and the amount used, is the most serious hazard in a FRP plant. The styrene and acetone are primarily absorbed by breathing the vapors although each can be absorbed through the skin upon contact. The exposure to styrene vapor occurs in the lamination areas located along the mold conveyor line. Exposure to acetone can occur during the purging of the spray nozzles or when transferring acetone from drums. Materials which may pose additional hazards to the workers include methyl ethyl ketone peroxide (MEKP), a catalyst, and acetone. The exposure to MEKP occurs to those persons mixing resins and to those exposed to the spray mist in lamination. MEKP can also cause skin burns and eye injuries. A summary of the legal and recommended levels for the previously mentioned substances and their health effects appear in Table I.

Central nervous system (CNS) effects have been observed among experimental subjects as well as workers exposed to styrene at time-weighted average (TWA) concentrations of about 100 parts per million (PPM). In addition, some investigators have reported observing these effects at concentrations less that 100 ppm, both experimentally and clinically. However, the experimental studies are of limited value in establishing a recommended exposure limit because of the small numbers of subjects studied. Similarly, the clinical studies are difficult to interpret because the exposures occurred over a wide range of concentrations, occasionally in excess of 100 ppm. The most frequently reported effects of exposures at about 100 ppm are subjective symptoms such as fatigue, dizziness, headache, nausea, poor memory, and drowsiness. These subjective symptoms of CNS depression have been substantiated experimentally in human subjects and in clinical studies of workers exposed to styrene who demonstrated slower reaction times and impaired balance; abnormal EEGs have also been noted.[4]

It has been reported in a number of clinical studies that chromosome changes occurred with greater frequency in the lymphocytes of workers exposed to styrene at about 100 ppm than among workers not exposed to styrene. Other investigators have reported an increase in the rate of sister chromatid exchanges among styrene-exposed workers. However, the long-term significance of these effects in not clear and requires further elucidation.[4]

Although the evidence is not strong, exposure to styrene has also been implicated with other adverse health effects such as peripheral neuropathy, abnormal pulmonary function, liver toxicity, teratogenicity, and carcinogenicity. These health effects need further investigation, and would provide additional evidence for a reduction in the current occupational exposure standard if they were found to be styrene-related.[4]

Table I. Summary of hazards associated with the production of small parts in the FRP industry

| Materials | OSHA PEL[a] (ppm) | ACGIH TLV[b] (ppm) | NIOSH[4] Recommended level (ppm) | Major Health Effects (more detail on styrene is in text) |
|---|---|---|---|---|
| Styrene | 100 | 50 TWA<br>100 STEL | 50 TWA<br>100 Ceiling<br>25 Action level** | Rapid CNS depression from high exposure (10,000 ppm); skin irritation[5] (more detail on styrene is in text) |
| Methyl ethyl ketone peroxide | | 0.2* | - | Accute local eye and skin irritation[6] |
| o-chlorotoluene | | 50 TWA<br>75 STEL | - | Toxic details unknown[7] |
| Acetone | 1000 | 750 TWA<br>1000 STEL | - | Skin defatting, solvent narcosis[8] |

* Ceiling limit, no established 8-hour TWA

** Action level for 8-hour TWA exposure (NIOSH) considers the probability that if a workers 8-hour exposure is at or above 1/2 the recommended standard, there is a significant risk that the worker's exposure level is above the recommended standard.

[a] Permissible Exposure Limit; this is the legally enforceable OSHA standard (29CFR 1910.1000)

[b] Threshold Limit Value, 8 hour TWA; this is a voluntary level recommended by the American Conference of Governmental Industrial Hygienists, 1984-85

## III. PLANT PROCESS AND DESCRIPTION

Plants for manufacturing small parts from fiber-reinforced plastic have layouts and equipment that varies with the type and size of the products. High volume production plants will tend to have continuously operating lines that divide labor on each item. This process allows a worker to remain in one location where control of the styrene vapor is most easily engineered. Other processes have batch production that gives each person the responsibility for producing a particular item from the beginning to the end of the production process. This second type is generally carried out in a booth or hood where the air flow is highly directional. In some cases, however, due to a large number of items being fabricated at one time, rather than rotate the molds into and out of the booths, the lamination is performed outside the booths. This manner of operation increases the chance of exposure to styrene and also the need for effective work practices and personal protective equipment.

### Plant A.

Plant A produces FRP bathtubs and shower stalls for the residential and motel/hotel market. The plant layout is shown in Figure 1. The plant employs over 50 full-time workers in a two shift operation, 16 of whom work directly with the lamination operation. About 130,000 #/month of polyester/styrene resin is used. The plant has a continuous operating line using an overhead mold conveyor system as shown in Figure 2. The product lamination takes place while the mold makes one lap of this oval conveyor track.

The first operation is the application of the gel coat. The gel coat is a finish quality pigmented resin applied to the mold surface in a layer about .025 mils thick. The gel coat is applied by spray gun to the mold by one of two operators in a partially enclosed section of the production line shown in Figure 3. The operators rotate the spraying assignment at one hour intervals with mold wiping/polishing. This is effective in reducing the styrene time weighted average (TWA) exposure. The color of the gel coat is determined by the gel coat supply line to which the spray gun is attached. Changing the gel coat color involves purging the spray gun with acetone to eliminate traces of the previous color. The level of acetone exposure was not a factor in this study, and it was not measured.

When the mold moves to the next station, a barrier coat is applied as shown in Figure 4. This is done in an enclosure similar to that used for the gel coat. The barrier coat is an additional layer of neutral colored resin, about 20 mils thick, that prevents surface markings from the chopped glass strands applied in the next step. There is only one worker assigned to this operation. His exposure to the styrene is not lessened by rotation with another worker as in the case of the gel coating operation. The mold moves through a short heated cure area, then to the first of two lamination areas, shown in Figure 5, where a layer of resin and chopped glass strand is built to a thickness of about 1/8 inch. Two operators alternate the spraying and roll-out operations. Carbon black is added to the resin to increase its opacity. In the second lamination area, shown in Figure 6, additional resin and bonded glass strand is added to a total thickness of about 1/4 inch.

Additional workers assist in resin roll-out and attaching reinforcing on the side panels and the base. After lamination, the tub or shower stall travels through a second cure area, is pulled from the mold and the mold is readied for lamination. The finished product is carted to a downdraft grinding booth, shown in Figure 7, where mold flashing is removed with a disc grinder.

Plant B:

Plant B is actually the small parts department of a larger boat building operation. This plant department is responsible for the lamination of flying bridges, shower stalls, deck lounges, hatches, fuel tanks, water tanks, battery boxes, pulpits, seat lids, and hull stiffeners. The molds for these items are evenly distributed throughout the work area as shown in Figure 10, which, as depicted, is further subdivided into tank and miscellaneous small parts areas. The parts are all prepared by hand lamination with the exception of some resin transfer molding in the northwest corner of the production area. This production area measures 210 feet by 61 feet, has a work area of 10,700 square feet and additional facilities, office and storage area of 2110 square feet. With the 15 foot ceiling, the work area has a volume of 160,560 cubic feet. The small parts production area ventilation system was redesigned in 1982 to increase the effectiveness in removing styrene from the work area. This was done by installing three ventilation booths, which are shown in Figures 11, 12, and 13.

## IV. CONTROL TECHNOLOGY

Principles of Control: Occupational exposures can be controlled by the application of a number of well-known principles, including engineering, work practices, personal protection, and monitoring. These principles may be applied at or near 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/equipment modification, isolation or automation, and 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 insure proper use and operating conditions, and the education and commitment of both workers and management to occupational health are also important ingredients of a complete, effective, and durable control system.

These principles of control apply to all situations, but their optimum application varies from case to case. The application of these principles at the plants is discussed below.

Engineering Controls:

Plant A.

This plant uses ventilation and styrene suppressed resins as styrene control methods. The principal control is the ventilation system. The design of the ventilation is a cross-flow, push-pull type. The lamination area is designed like a tunnel so that air blown across the spray-on area goes directly into the exhaust air vents. The movement of the resin spray during the walk-through survey, in the lamination areas indicated that the velocity there was adequate to collect the styrene vapor. During the period between the preliminary and in-depth surveys, the company installed a vapor incinerator, shown in Figure 8, to reduce the styrene level in the exhaust stack, a change necessary to meet a State air pollution limit of 100 tons of volatile organic compounds per year. To build up the styrene concentration in the incinerator chamber, the ventilation in the gel coating and barrier coating areas was reduced 75% to 5000 CFM.

It was apparent during the survey from the odor of styrene and the eye irritation, that the present air flow rates in the gel coating and barrier coating areas could not prevent back-spray from contacting the spray gun operator. The intent of the company was to rely on respirators for worker protection in these areas. The exhaust air vents are covered with glass fiber filter media which is changed twice each day. The inlet (push) fans are located on the ground level while the exhaust (pull) fans are located on the roof. The roof ventilation ductwork is shown in Figure 9. The flow rates in the roof ductwork and in the air supply ducts were obtained by velocity traverses with the Kurz hot-wire anemometer. Data for the velocity traverses is shown in Appendix A. There are three large exhaust fans for the lamination areas that vent to the roof ductwork; one exhaust fan each for the gel and barrier coat areas that vent to the vapor incinerator, and one smaller exhaust fan for the grinding booth that vents through a 20" diameter duct to a separate stack on the roof. The outlet ducts for all exhaust fans join just before entering the exhaust stack. Two additional large fans supply outside air to the exhaust stack to increase the effective stack height and to further dilute the styrene vapors. During the walk-through visit, the total exhaust air flow was stated, by the company, to be 69,300 CFM compared to a design goal of 86,500 CFM.

The grinding booth is a source of resin dust generated when the mold flash is trimmed from the finished part. This is considered a nuisance dust for regulatory purposes. There was no plant exposure data available for this operation. A sample pump with a filter cartridge was placed on the grinder operator during each day. The average of the total dust exposure for the three days is 24 $mg/m^3$ which is above the 15 $mg/m^3$ PEL for nuisance dust established by OSHA. The make-up air in the grinding booth (supplied from the room air) was also checked for dust. This was found to be about 7.0 $mg/m^3$ which is about 50% of the PEL. The filter media in this system is fiberglass battens such as used in home heating systems. This type of filter is inefficient for use in controlling the resin dust. The grinder operator does however wear a supplied air respirator.

Plant B.

The hull lamination and assembly areas of the plant are ventilated by air make-up units (AMU) and by ground level exhaust blowers which remove the styrene fumes through the wall ports. The exhaust blowers are shown in Figure 14. The small parts department production area, which has three levels, is located along the long axis of the lamination and assembly building as shown in Figure 15. All lamination is done on the first or ground level.

The ventilation to the small parts lamination area, which was redesigned in 1982, is provided by three AMU located on the 3rd level, two of which supply a total of about 120,800 CFM of air to the first floor, and a third AMU which supplies 49,000 CFM of air to the 2nd floor.

There are three lamination booths in the small parts work area as shown in Figure 16.

Air exhausted through the booths is considerably less than the supply air and the excess vents into the hull lamination and finishing areas of the plant. Of the 120,800 CFM total supply air to this work area a total of 32,000 CFM is received by booths 1 & 2. The remainder, 37,900 CFM, ventilates the area containing booth 3. This flow arrangement is shown in Figure 16. The calculated average air velocity toward booths 1 & 2 is 37 FPM. This velocity is not high enough to overcome the room air turbulence generated by point source supply air inlets and worker comfort fans. This situation results in unpredictable air flow patterns in the work area.

A similar situation exists in the work area containing booth 3, extending from the rest room to the mixing room. This area receives ample supply air so that most styrene is displaced into the hull lamination area outside of the small parts department.

The face velocity of air entering booth 1 was measured with the rotating-vane anemometer. The average face velocity was determined to be 130 FPM. This velocity is considered adequate to contain styrene vapor within the booth. It was noted that although the three ventilation booths were ideal for spray-up and roll-out lamination, the molds were not rotated in and out of the booths to take advantage of this.

Work Practices:

Plant A:

The floor is covered with clean kraft paper each day and the waste paper is thrown into a dumpster outside the building. The exhaust filters are changed two times each day to maintain the efficiency of the ventilation system. Each new employee, upon hiring, is given a training course in work practices.

Plant B.

The employees in the small parts work area are apparently aware of the need to work upwind of the resin roll-on operation. By working on the side of the mold away from the booths, the drift of air toward booths 1 and 2 should reduce the exposure to styrene. The fiberglass filters on the exhaust air inlets of the booths occasionally become clogged and require changing. The use of comfort fans in the work area during warm weather generates considerable air turbulence which affects the effectiveness of the ventilation system.

The gel coat is sprayed on the molds and is done in the open work area. This operation should be carried out in the booths to limit the contamination of the general work area by styrene vapor. When resin was blended with catalyst for roll-on lamination work, the blending was not carried out in the booths but was done in the work area. This also will contribute to styrene exposure.

Personal Protective Equipment:

Plant A:

Workers in the lamination area wear coveralls and were observed wearing disposable 3M particulate respirators. This type of respirator seems to be adequate because of the low styrene levels observed. Workers in the gel coat and barrier coat areas wear MSA #OV 464031 quarter face mask type respirators, which is approved for use against organic vapors. The operator in the grinding booth wore a 1/4 face disposable dust-filter respirator.

Plant B.

The gel coater was observed to always wear a respirator while performing his task. The use of respirators by other workers was not observed but respirators are available to the workers from the Safety Department. Workers in the lamination area wear old clothes provided by the company. The workers are provided with protective gloves and safety glasses. A protective barrier creme, Gel 9 (by Mallard), is made available to the workers to protect skin from irritation by styrene and acetone.

It was reported by the Safety Manager that workers receive periodic refresher instruction in the use of good work practices and the use of personal protective equipment.

Monitoring by Company:

Plant A:

This plant has regularly scheduled in-plant industrial hygiene surveys performed by company personnel. Results from an industrial hygiene survey performed by a company chemist on February 17, 1983 indicated that the average TWA exposure for 9 employees in the lamination area was 22.7 ppm styrene. The range of employee exposure was 8 ppm for the parts repairman to 34 ppm for the barrier coat operator. This monitoring test was performed prior to the installation of the vapor incinerator which required altering the air flow to the gel coat, barrier coat, parts cooling and part pulling work areas.

Plant B:

The industrial hygiene sampling of plant facilities is overseen by the industrial hygienist of the parent company. No sampling results were requested or supplied by the company.

## V. METHODOLOGY FOR IN-DEPTH SURVEY

Measurement of Control Parameters: Air flow measurements were limited to the determination of total volumetric air flow exhausted by lamination booths and traverses at key points in the air supply ductwork. Air velocity was determined using either a pitot tube or calibrated hot-wire anemometer according to the procedures outlined in Industrial Ventilation: A Manual of Recommended Practice.

Sampling Procedures:

General Procedures -- As an index of control effectiveness, personal and area styrene samples were obtained. Using personal samples, the 8-hour time-weighted average (TWA) concentration of styrene vapor was determined for the gel coat spray-gun operator and other selected lamination workers. The samples indicate exposure a worker would receive without a respirator. The styrene was collected in tubes containing charcoal (150 mg), using personal sampling pumps operated at 10, 20 or 200 ml/min depending upon the type of sample taken. Area samples for styrene were obtained on a selective basis using a similar apparatus.

The equipment used in the study is listed in Table II.

Table II: Equipment items used in the study

| Item | Model | Use |
|---|---|---|
| Sampling pumps | MDA Accuhaler | Styrene vapor |
| | Du Pont P2500 | dust |
| Draeger styrene detector tubes | | Styrene vapor |
| Hot-wire anemometer | TSI model 1650 | Air velocity |
| Pitot tube | Dwyer | Air velocity |
| Rotating vane anemometer | Davis #50400B | Air velocity |

Plant A.

In Plant A, the 8-hour TWA styrene exposure concentrations were determined for each gel coat and barrier coat operator and other selected lamination workers. Separate morning and afternoon personal samples were collected outside the respirator (where used). for the in-depth survey, the 9 employees who worked on the lamination line were sampled for two periods during the work day. No sampling was performed during the lunch period. Each personal sample time was nominally 3 1/2 hours (210 min) and ranged from 185 to 210 minutes. Sampling began about 8:30 am and ended about 2:00 PM. This allowed for sampling during the most active portion of the first shift. A total of 54 personal samples were taken for styrene. Area sample points were selected to indicate styrene concentration in the center and edge of the work area. Thirteen personal samples for resin dust exposure in the grinding booth were taken using Du Pont P2500 pumps and 5 micrometer PVC membrane filters. A few personal samples for grinder dust were obtained in the deflashing booth.

Area samples for styrene vapor were obtained in the gel coat and barrier coat areas. The styrene concentration appeared very high at times as indicated by odor, eye irritation or direct reading instruments.

Plant B.

In Plant B, the 8-hour TWA concentrations of styrene were determined by morning and afternoon samples, which were approximately 4 hours in duration, on the first and third days. No sampling was performed during the lunch period. On the second day, sample periods of thirty minutes in duration, were used to obtain styrene exposure data on three of the lamination workers, while at the same time, work practices were noted at one minute intervals. This was done to attempt to establish a relationship of styrene exposure with the observed work practices of the workers. This approach had not previously been attempted by this work group so there was no assurance that the outcome would be useful.

Area styrene samples were obtained at two points in the work area as noted on Figure 10. Styrene concentrations were spot checked with Draeger™ detector tubes to determine the approximate concentrations in the vicinity of lamination work. The area sampling sites were selected to estimated the concentration of the styrene vapor after it had mixed with the work room air.

## VI. RESULTS OF SAMPLING

The field studies involved making air velocity measurements on the ventilation systems and determining concentrations of styrene in the ambient workplace air. To determine control effectiveness, the study focused on obtaining personal samples on the lamination workers, and also the background levels of styrene at selected points in the plant.

Ventilation--Ventilation measurements were made with either a Kurz or TSI hot-wire anemometer, and in one case, with a pitot tube. The hot-wire anemometer was preferred because most air flow encountered was turbulent or of very low velocity. The hot-wire anemometer is generally better suited for this situation.

Results of Personal and Area Sampling:

Plant A.

A total of 52 personal samples for styrene were obtained. Also, 12 area samples for styrene and 13 personal samples for grinder dust were obtained. The results of the personal sampling for styrene are shown in Table III. The workers are coded A to I. The styrene concentration is the mean of 3 8-hour TWA.

Table III. Styrene concentration, personal samples, Plant A

| Worker | Job Title | Styrene Average Concentration* | Standard Deviation |
|---|---|---|---|
| A | Gel Coater | 87 | 18 |
| B | Gel Coater | 79 | 13 |
| C | Barrier Coater | 170 | 20 |
| D | Chopper Gun Op., Lam #1 | 38 | 11 |
| E | Roll Out Lam #1 | 50 | 16 |
| F | Chopper Gun Op., Lam #2 | 58 | 10 |
| G | Chopper Gun Op., Lam #2 | 50 | 6 |
| H | Roll Out Lam #2 | 49 | 10 |
| I | Chopper Gun Op., Lam #1 | 52 | 7 |

* The Styrene concentration reported is the average of 3, 8-hour TWA values

The sampling data obtained for Plant A personnel indicates that the OSHA PEL is being met with the exception of the Barrier Coater. A comparison of the sampling data with the NIOSH recommended 8-hour TWA for styrene makes it doubtful that any of the workers sampled would be consistently below the recommended level of 50 ppm and all would be above the 25 ppm styrene action level. It is also to be noted that the exposure level of the Barrier Coater is above the NIOSH and ACGIH STEL of 100 ppm styrene.

The styrene concentrations, based upon previous information and impressions obtained in the preliminary survey in February 1983, are higher than anticipated for the gel coaters and barrier coaters. The company obtained personal sample data in their own survey in February, 1983. These data are shown in Table IV. It should be noted that NIOSH data indicates an average exposure about double that of the company data.

Table IV: Company personal sampling data, February, 1983, Plant A

| Job title | Styrene concentration 8-hour TWA, ppm |
|---|---|
| Gel Coater | 21 |
| Barrier Coater | 34 |
| Chopper Gun Op., Lam #1 | 32 |
| Roll Out, Lam #1 | 26 |
| Trimmer | 19 |
| Chopper Gun Op., Lam #2 | 21 |
| Roll Out, Lam #2 | 28 |
| Parts Puller | 15 |
| Parts Repair | 8 |

The great differences in the exposure of the gel coaters and barrier coaters reflects the change in the ventilation system when the vapor incinerator was installed. Different plant operating conditions and different operators may also have contributed to the difference.

The area samples obtained in the gelcoat and barrier coat areas indicate a high level of styrene. These data are shown in Table V. It should be noted that the personal samples for the gel coating operators is higher than the area sample. In the case of the barrier coat operator, the area and personal samples are approximately the same. It is not expected that the area and personal samples will agree at all times. The area samples are set near the work area not knowing with certainty how the process materials will be distributed or channeled by air currents. Detailed sampling results are listed in Appendix A.

Table V: Styrene concentration in gel and barrier coat areas*, Plant A

| DAY | Gel Coating (ppm Styrene) | Barrier Coating (ppm Styrene) |
|---|---|---|
| 1 | 49 | 123 |
| | 62 | 80 |
| 2 | 66 | 192 |
| | 64 | 249 |
| 3 | 61 | 167 |
| | 58 | 218 |
| Average | 60 ± 6 | 171 ± 62 |

*Average sample time was 200 minutes

Plant B.

A total of 65 personal samples for styrene were obtained plus an additional 12 area samples. The results for the personal samples are shown in Table VI. The sample data are shown in Appendix B.

Table VI. Styrene concentration, personal samples

| DAY | JOB TITLE | SAMPLE TIME hours | STYRENE CONC. ppm | STYRENE AVG. CONC. ppm | STANDARD DEVIATION |
|---|---|---|---|---|---|
| 9/13 | Worker A | 9.2 | 8 | | |
| 9/14* | Group | 8.0 | 18 | 13 | 5 |
| 9/15 | Leader | 7.6 | 14 | | |
| 9/13 | Worker B | 9.1 | 36 | | |
| 9/14* | Laminator | 7.5 | 42 | 47** | 14 |
| 9/15 | | 7.7 | 62 | | |
| 9/13 | Worker C | 3.9 | 13 | | |
| 9/14* | Laminator | 7.8 | 22 | 23 | 11 |
| 9/15 | | 4.2 | 35 | | |
| 9/13 | Worker D | 3.9 | 12 | | |
| 9/14 | Tank Lam. | 7.9 | 14 | 14 | 3 |
| 9/15 | | 7.7 | 17 | | |
| 9/13 | Worker E | 0.4 | 74 | - | - |
| 9/14 | Gel Coater | 0.5 | 63 | - | - |

* Data taken on day 2 for workers A, B, and C, was for half-hour sample periods, consolidated here to represent a TWA for the workday.

** The high standard deviation for this worker indicates that the exposure might be above the NIOSH recommended TLV of 50 ppm Styrene, 8 hour TWA.

The sampling data obtained for plant B indicates that all worker exposure to styrene is below the OSHA PEL of 100 ppm at the 99% confidence level but only worker D would be below the NIOSH recommended 8-Hour TWA of 50 ppm at the 99% confidence level and all worker exposures would be above the NIOSH action level at 25 ppm styrene.

A statistical Analysis of Variance (ANOVA) was performed on the half-hour sample data collected on day 2. Only workers A, B, and C were included in this particular sample series. These data include minute by minute observations of work practices that relate to styrene exposure. Those factors selected were Laminating (L), Other Work (O), Resting (R), Upwind

(U), Downwind (D), Inside of Booth (I), Near Booth (N), and Far From Booth (F). The Near Booth (N) zone was defined as that area between the face of the booth and the first building support in the upwind direction, a distance of about 10 feet. Spraying (S), was included in the factors observed but only one worker (D), performed this and only one sample was taken so no correlation is possible. The exposure data for these factors was plotted with the SAS computer printout. The linear regression analysis was performed on each set of data and a correlation coefficient was calculated. These graphs are placed in Appendix C.

The area sampling data for styrene are shown in Table VII.

Table VII. Area sample data, Plant B

| DATE | SAMPLE TIME hours | SAMPLE LOCATION | STYRENE CONCENTRATION ppm |
|---|---|---|---|
| 9/13 | 4.3 | See footnote 1. | 20 |
| 9/13 | 5.9 | " | 11 |
| 9/13 | 4.1 | See footnote 2. | 10 |
| 9/13 | 5.9 | " | 5 |
| 9/14 | 4.2 | See footnote 1. | 1 |
| 9/14 | 5.6 | " | 1 |
| 9/14 | 4.3 | See footnote 2. | 7 |
| 9/14 | 5.5 | " | 3 |
| 9/15 | 3.6 | See footnote 1. | 3 |
| 9/15 | 5.5 | " | 10 |
| 9/15 | 3.6 | See footnote 2. | 7 |
| 9/15 | 3.3 | " | 6 |

1. This sample site is in a doorway near booth #2 and between the small parts area and the hull lamination area. (See Figure 10)

2. This sample site is on a column in the small parts area and between booths #1 and #2. (See Figure 10)

# VII. CONCLUSIONS AND RECOMMENDATIONS

Plant A.

This plant was well designed to control styrene vapor for the original production schedule of one shift operation. This was apparent in the preliminary survey in March 1983 and is supported by personal sampling data obtained by the company in February 1983. The redesign of the ventilation system for the barrier and gel coating areas was brought about by the scheduling of a second production shift. As a result of this survey it was realized that the installation of the styrene vapor incinerator drastically increased the styrene exposure level in the gel and barrier coating areas and to a lesser extent in the laminating areas. This has changed what appeared to be a well designed cross flow ventilation system into one which marginally meets the PEL of 100 ppm styrene in the gel and barrier coating areas and substantially raises the exposure of the lamination workers. It is doubtful that any of the workers sampled would be consistently below the NIOSH recommended level of 50 ppm and all would be above the 25 ppm action level. The Barrier Coater is also above the NIOSH and ACGIH STEL of 100 ppm. In the case of the lamination workers, it is not clear why the exposure has almost doubled since the ventilation flow rates in the lamination areas did not change significantly due to the installation of the styrene vapor incinerator. It is concluded that because of the increase of styrene exposure in the barrier and gel coating areas, the reduced ventilation in those areas is an unsatisfactory approach to meeting air pollution emission standards. It is acknowledged that 20,000 CFM is a large volume of air to treat by incineration, adsorption, or absorption but other approaches to removing styrene from the exhaust air should be examined. An interim approach for the Gel and Barrier Coat workers to avoid eye irritation would be to provide them, as a minimum, with full facepiece organic vapor chemical cartridge respirators as specified in the NIOSH <u>Criteria for a recommended standard···occupational exposure to styrene</u>.[9] It was recommended that this problem be discussed with their State Department of Air Resources and the State or Federal occupational health regulatory authorities.

The barrier coater has the highest exposure of all the workers and experienced an apparent fivefold increase in styrene exposure due to the modification in the ventilation system. Other factors such as work practices or production rate may have contributed to this increase. It could be the result of the barrier coater working continuously in the spray area whereas the gel coaters alternate between spray and mold preparation. This reduces the average exposure of the gel coaters to about one-half that of the barrier coater.

Plant B.

The ventilation system for the small parts production area of this plant was redesigned and altered in 1982 to improve the working conditions for the employees. The three booths installed would permit the lamination of parts within an enclosed space and would offer better protection from styrene vapor if good work practices are used. The intensive use of the work space however does not permit the rotation of molds in and out of the booths. It is apparent from the number of parts that are routinely made in this shop that it would be impractical to move the molds about during lamination without creating confusion in an otherwise orderly procedure. The styrene exposures of the workers indicates that 1 of the 14 sample days was above the NIOSH recommended level of 50 ppm styrene. Two 1/2 hour samples (9/13 & 9/14) for worker E, Gel Coater, were above the NIOSH recommended TWA Criteria of 50 ppm, but are not representative of 8 hour TWA exposures. The Gel Coater was observed to wear a respirator while spraying.

The area samples indicate that the styrene concentration in the two selected areas of the plant did not exceed 20 ppm for a 4 hour period or 16 ppm for an 8-hour workday. Since one point was selected to sample air leaving the production area and the other to sample air in the middle of the work area, it is safe to conclude that the styrene concentration in the work area is generally below 50 ppm styrene. The reason for this low level is probably due to the high air flow rate through the work area. The area containing booths #1 and #2 has the air changed every 2 minutes and the other work area containing booth #3 has the air changed each minute. About 58% of this small parts department supply air vents into the general plant area.

The lamination workers are instructed in good work practices but it was not easy to observe to what extent they were observing them. The experiment on September 14 of taking half hour personal samples, was to obtain some measurement of the effect of work practices. The analysis of the data indicates that worker exposure is a function of time spent laminating and the time spent upwind and downwind of the lamination surface. The correlation of the resin application data for upwind (RU) and downwind (RD) is reversed for workers B and C as compared to worker A. This is evident from the increase in styrene exposure level as the proportion of time upwind is increased. This may be the result of assuming that the air flow in the room was in the direction of booths #1 and #2 while eddy currents generated by the air supply inlets altered the direction. Worker exposure data do not correlate well with the location of the workers in relation to the booths. These locations are noted by, In the booth (I), near the booth (N), and far from the booth (F). This lack of correlation is also apparently due to the air turbulence in the room which overrides the assumed direction of air flow and suggests that there are, at times, points of high concentration of styrene in the work area due to patterns of air currents.

Although this plant has achieved good control of styrene exposure in the small parts production area, the exposure could probably be further reduced. For example, if it is assumed that the higher level of exposure of worker B compared to the other laminators is the result of work practices, improved work practices could lower the average styrene exposure.

Better use should be made of the booths to reduce the exposure of the workers and the gel coater in particular. This recommendation is made without knowledge of production problems that would occur if molds need to be moved about during the work shift.

Workers should receive periodic refresher instruction in the use of good work practices and the use of personal protective equipment to encourage them to use some extra effort to avoid exposure to styrene.

## VIII. REFERENCES

1. International Labour Office, 1972, Encyclopedia of Occupational Health and Safety, Vol. II, McGraw-Hill Book Company, New York, New York.

2. Bourne, L. B. & Milner, F. J. M. 1963, Polyester Resin Hazards, British Journal of Industrial Medicine, 20: 100-109.

3. Brooks, S., Associate Professor of Environmental Health and Medicine, Kettering Laboratory, University of Cincinnati; "Investigation of Workers Exposed to Styrene in the Reinforced Plastic Industry." 1979, 330 pp. This study was performed for the Society of Plastics Industries.

4. Criteria for a recommended standard····occupational exposure to styrene, DHHS(NIOSH) Publication No. 83-119, Department of Health and Human Services, National Institute for Occupational Safety and Health, September, 1983., Pages 1-2.

5. Sax, Toxicology 1968, Page 1013

6. Sax, Dangerous Properties of Industrial Materials, 4th Ed., Van Nostrand Reinhold, 1075, page 923.

7. Ibid., page 557

8. Ibid., page 352

9. Criteria for a recommended standard····occupational exposure to styrene, DHHS(NIOSH) Publication No. 83-119, Department of Health and Human Services, National Institute for Occupational Safety and Health, September, 1983., Table I-1, Page 8.

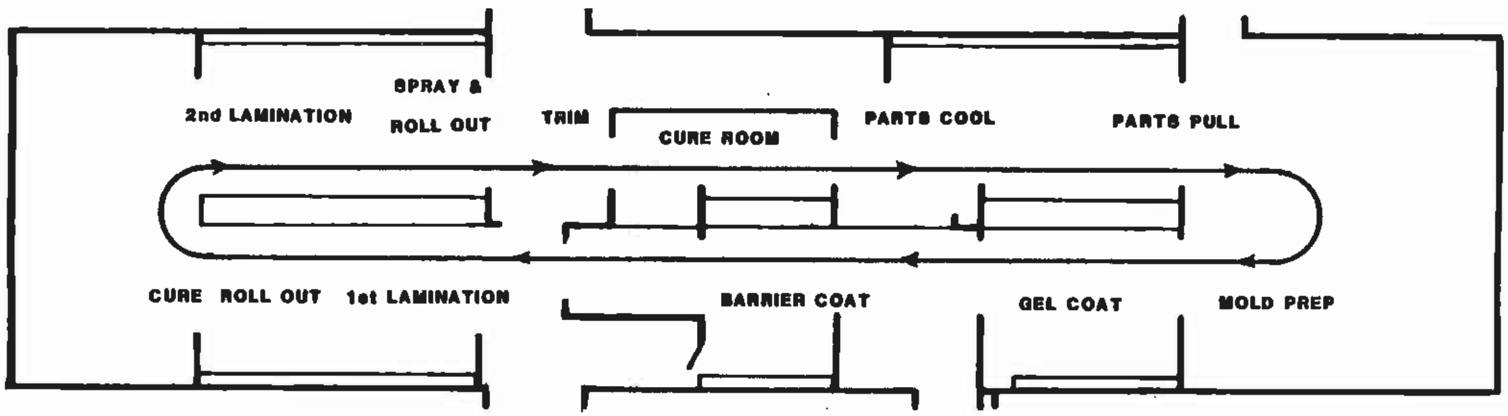



FIGURE 1. PLANT A - LAYOUT

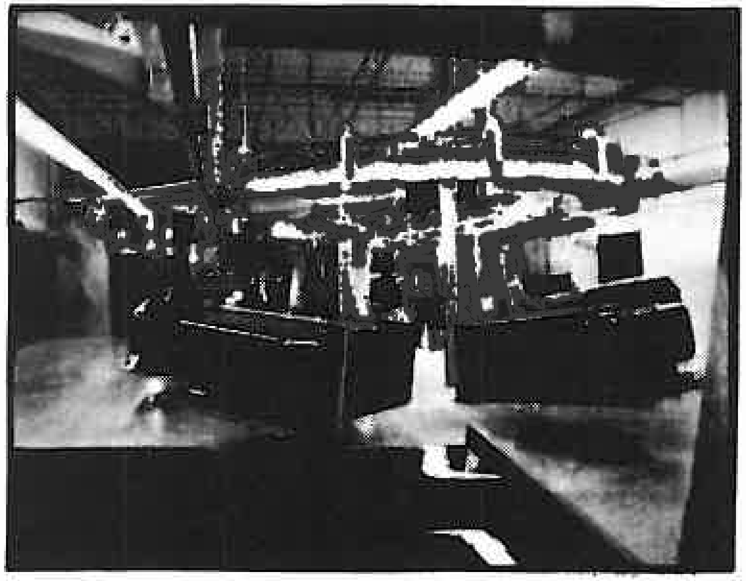


FIGURE 2. MOLD CONVEYOR SYSTEM

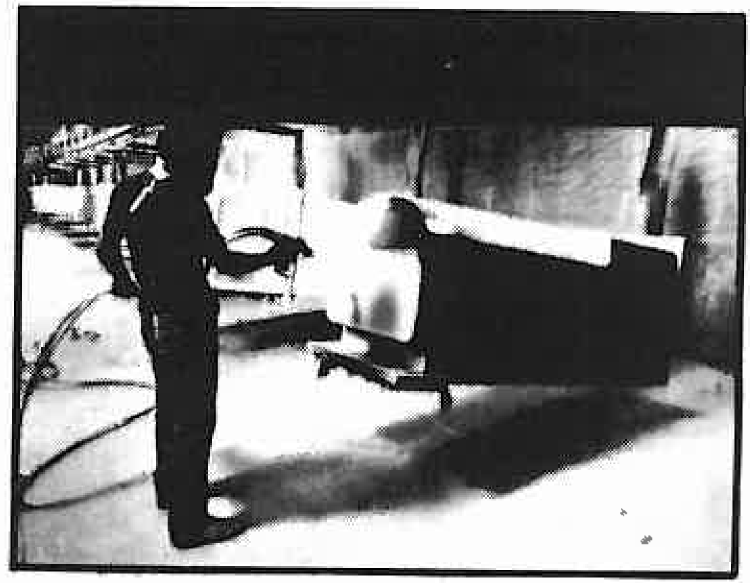


FIGURE 3. GEL COAT AREA

( PLANT A )

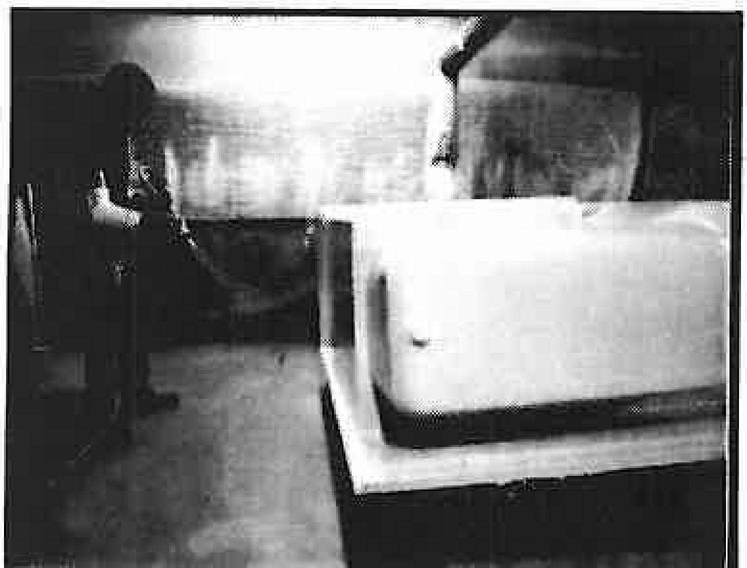


FIGURE 4. BARRIER COAT AREA

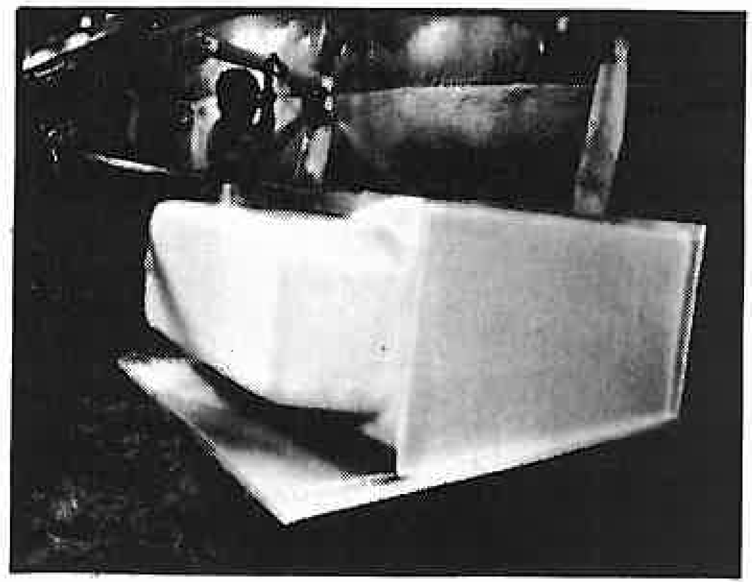


FIGURE 5. LAMINATION AREA 1

( PLANT A )

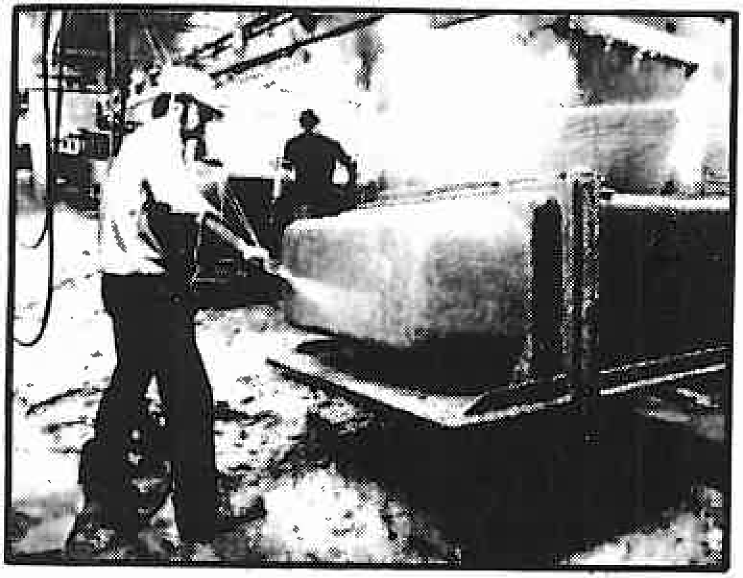


FIGURE 6. LAMINATION AREA 2

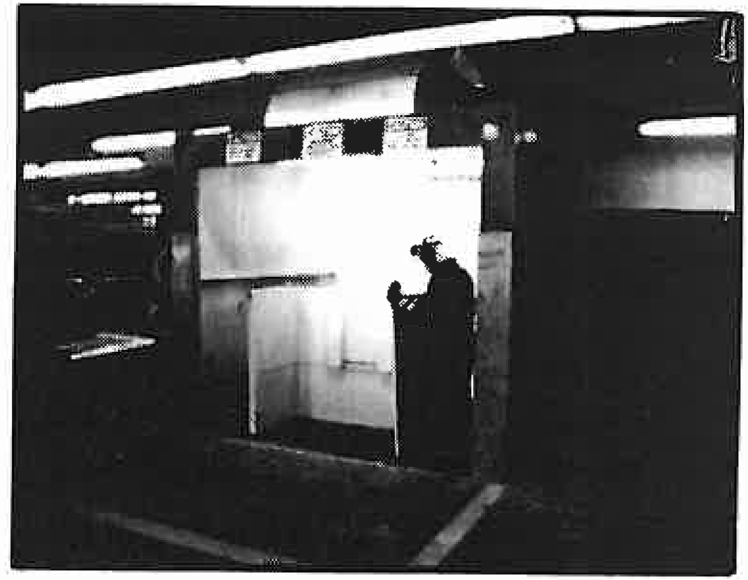


FIGURE 7. GRINDING BOOTH

( PLANT A )

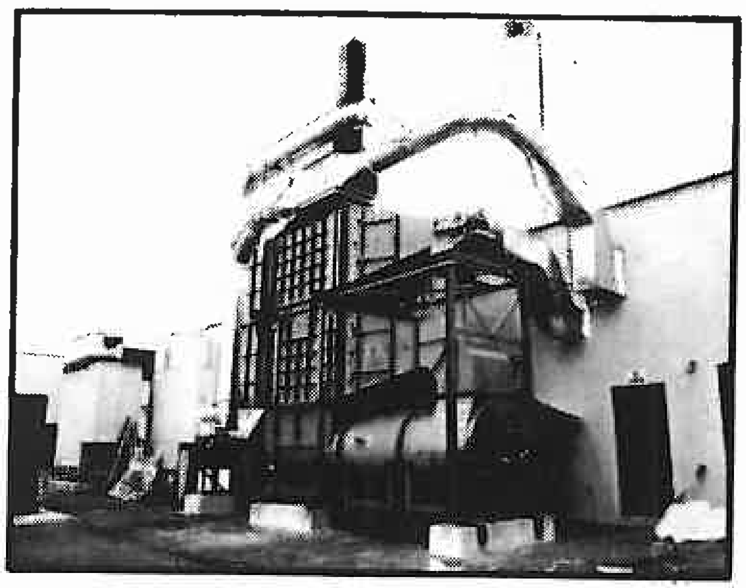
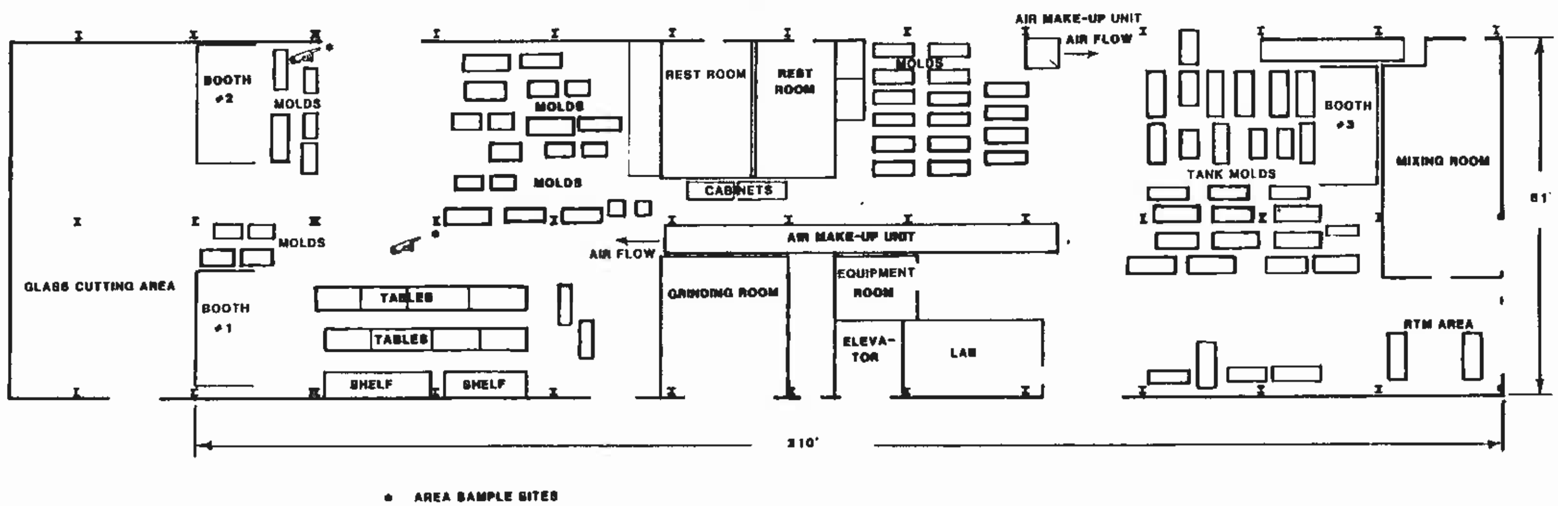


FIGURE 8. VAPOR INCINERATOR

FIGURE 9. ROOF DUCTWORK

( PLANT A )

FIGURE 10. PLANT B LAY-OUT (SMALL PARTS DEPARTMENT)



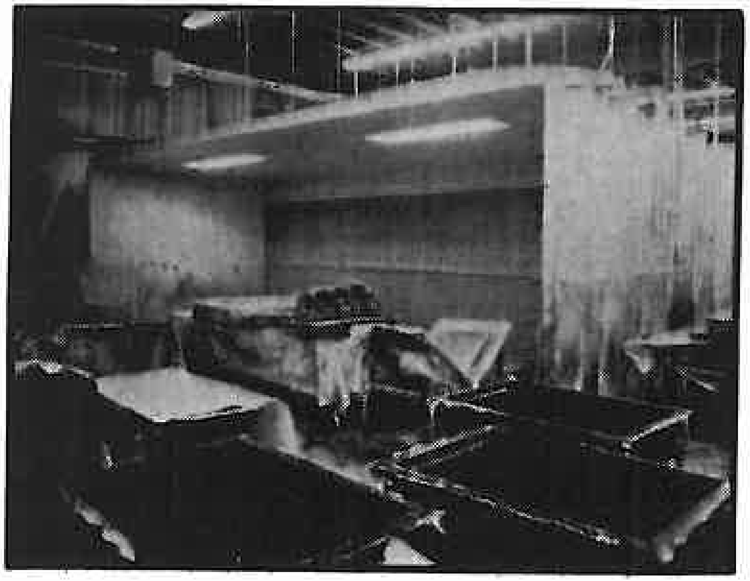


FIGURE 11. BOOTH 1, SMALL PARTS AREA

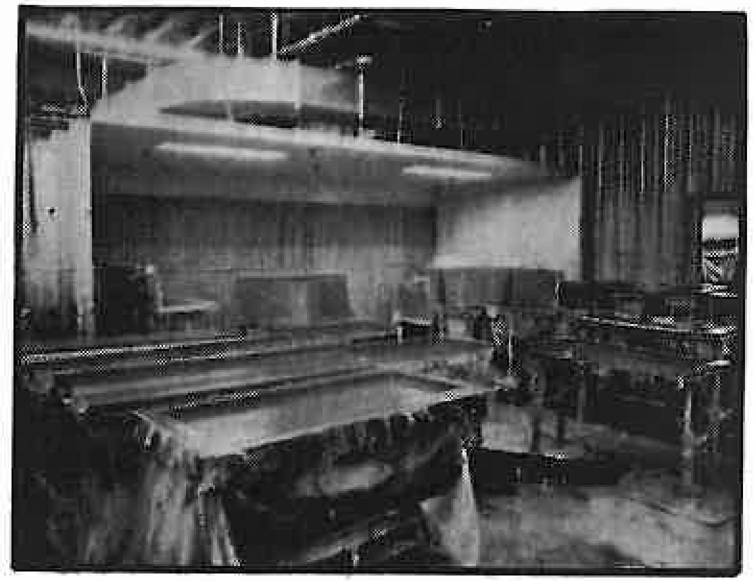


FIGURE 12. BOOTH 2, SMALL PARTS AREA

( PLANT B )

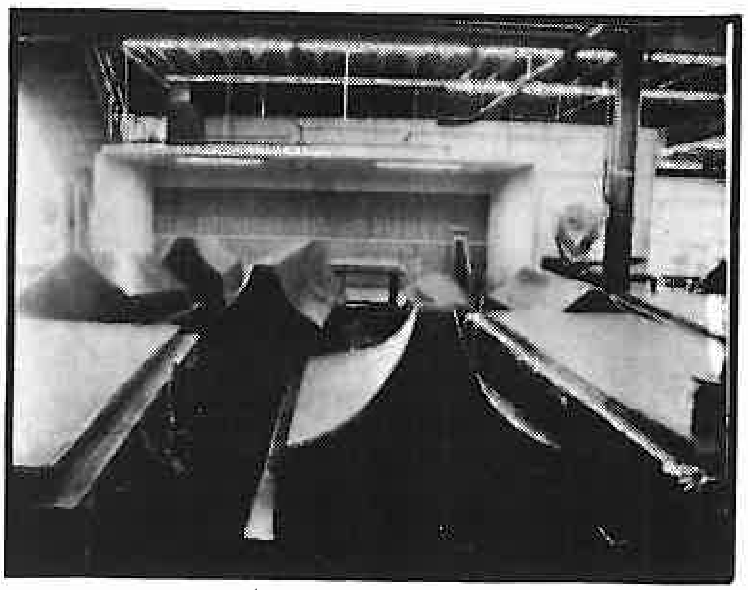


FIGURE 13. BOOTH 3, SMALL PARTS AREA

FIGURE 14. MAIN PLANT EXHAUST BLOWERS

( PLANT B )

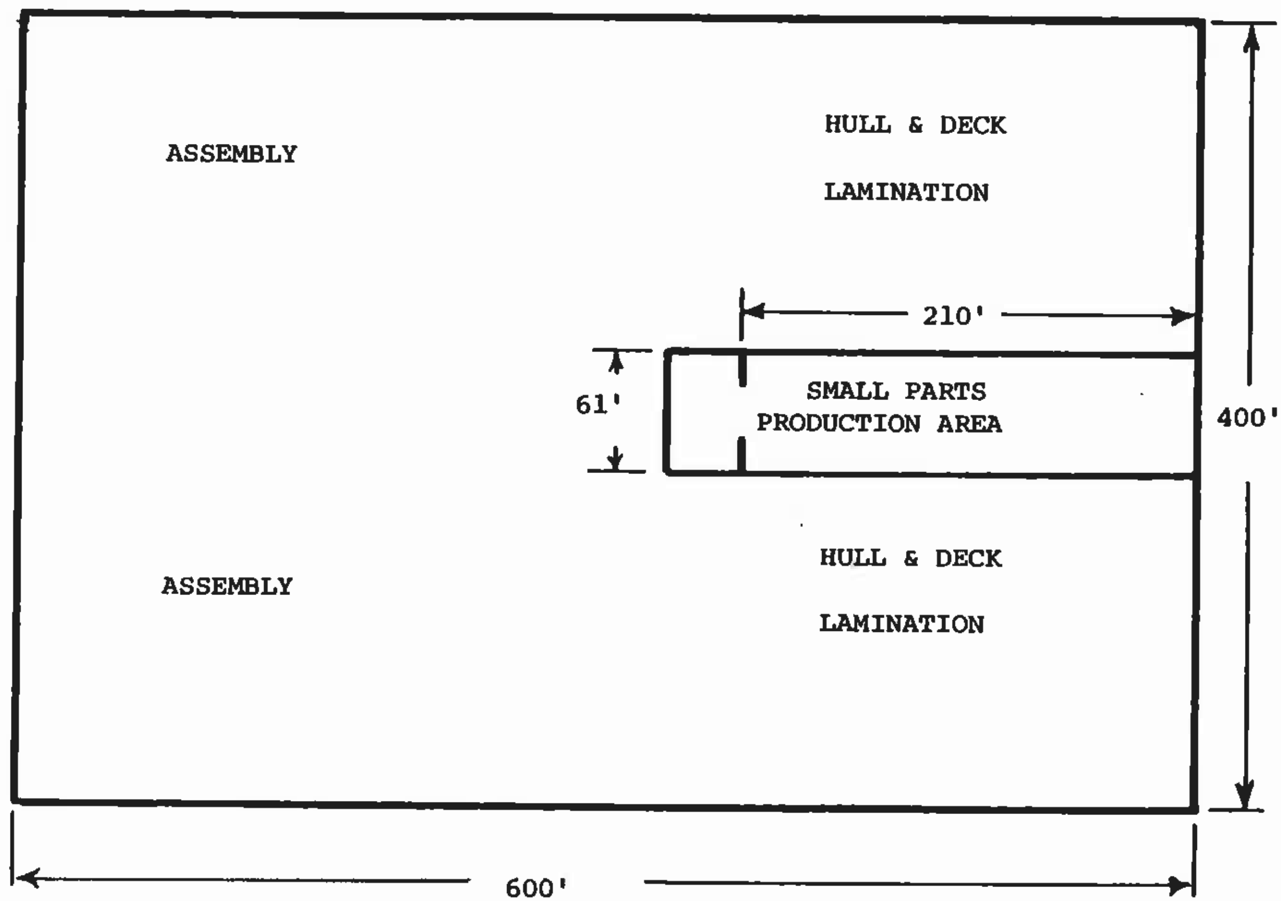
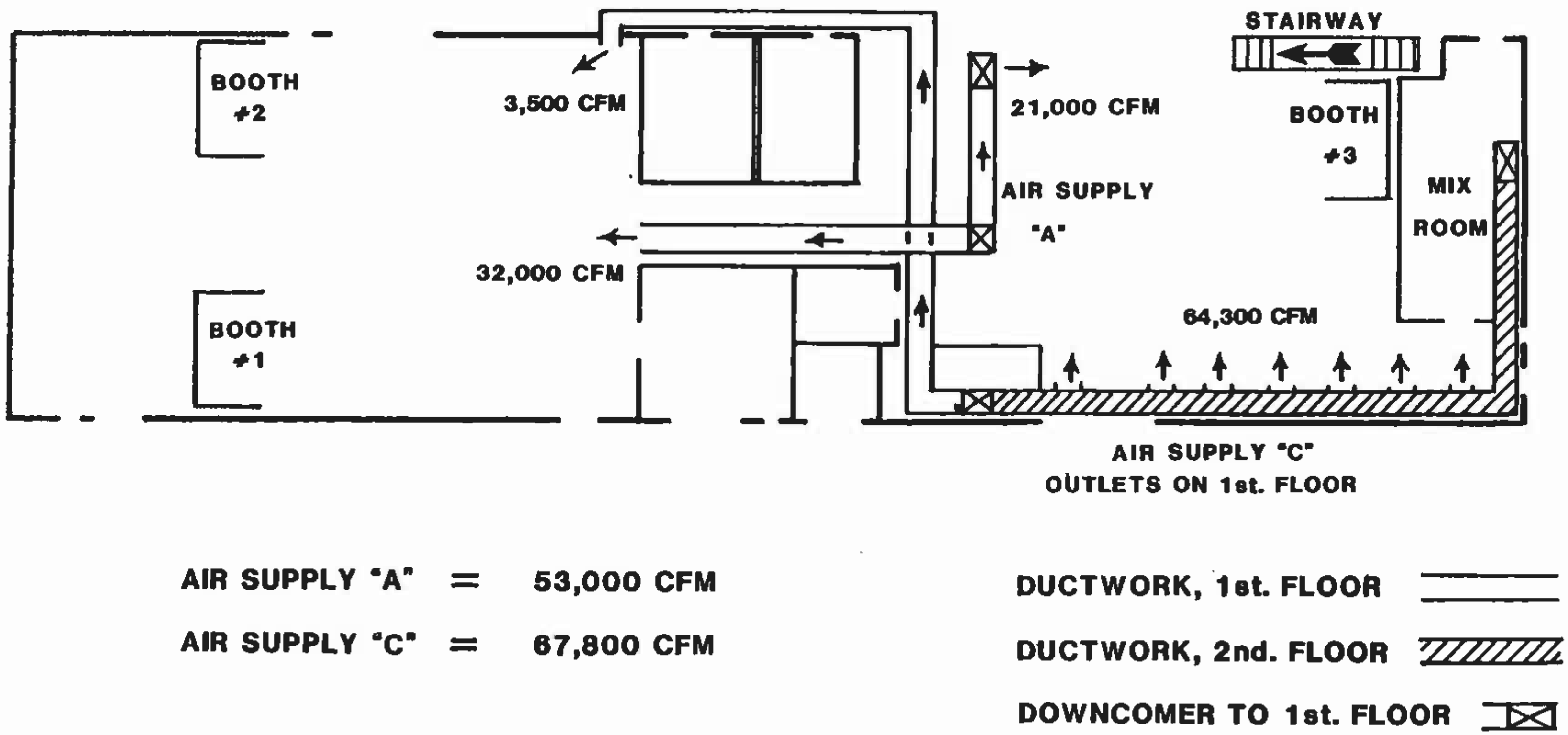



Figure 15. Location of small parts production area

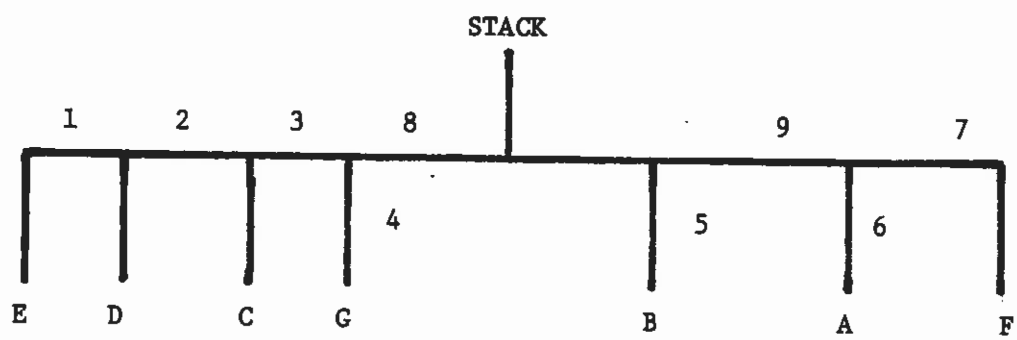
FIGURE 16. SUPPLY AIR DUCTWORK TO SMALL PARTS WORK AREA



## XIX. APPENDIXES

### Appendix A-1 Ventilation data for Plant A.

1.a Flow data for roof ducting system by NIOSH survey team. 6-9-83



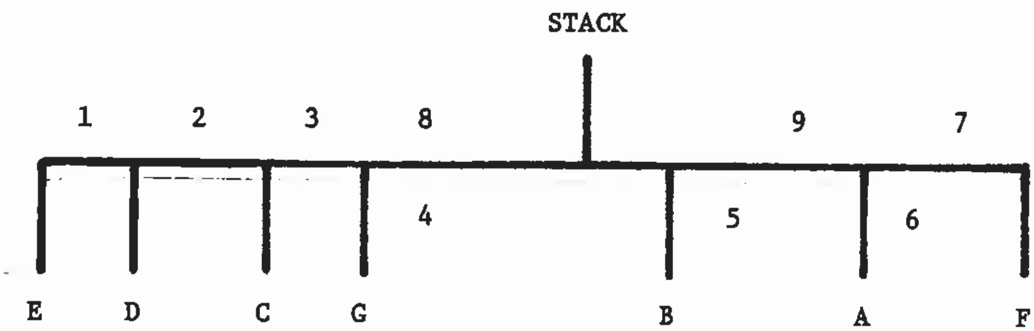

Blowers indicated by A to G

Data obtained from velocity traverse

| DATA POINT | DUCT SIZE in. | DUCT AREA $ft^2$ | AVERAGE VELOCITY FPM | FLOW RATE CFM | COMMENTS |
|---|---|---|---|---|---|
| 1 | 31 x 18 | 3.875 | | 11,500 | By difference |
| 2 | 48 x 31 | 10.33 | 2400 | 24,800 | |
| 3 | 48 x 52 | 17.33 | | 39,900 | Same as point #8, #4 is 0 |
| 4 | 12 x 10 | 0.835 | 0 | 0 | Duct plugged with debris |
| 5 | 48 x 16 | 5.33 | 2033 | 10,800 | |
| 6 | 40 x 24 | 6.67 | | 15,200 | By difference, #9 - #7 |
| 7 | 20 x 8 | 1.11 | | | |
| 8 | 52 x 48 | 17.33 | 2303 | 39,900 | |
| 9 | 48 x 24 | 8.00 | 2272 | 18,200 | |

The stack flow is 68,900 CFM, the sum of #5, #8 and #9

1.b Flow data for roof ducting system by contractor, exact date unknown




Blowers indicated by A to G

Data was marked on roof ductwork

| DATA POINT | DUCT SIZE in. | DUCT AREA ft$^2$ | AVERAGE VELOCITY FPM | FLOW RATE CFM | COMMENTS |
|---|---|---|---|---|---|
| 1 | 31 x 18 | 3.875 | 3613 | 14.000 | |
| 2 | 48 x 31 | 10.33 | 3194 | 33.000 | |
| 3 | 48 x 52 | 17.33 | 3001 | 52,000 | |
| 4 | 12 x 10 | 0.835 | 1800 | 1500 | |
| 5 | 48 x 16 | 5.33 | 2064 | 11,000 | now pulls ambient air |
| 6 | 40 x 24 | 6.67 | 3120 | 18,000 | now pulls ambient air |
| 7 | 20 x 8 | 1.11 | 2700 | 1,000 | |
| 8 | 52 x 48 | 17.33 | | | no data on ductwork |
| 9 | 48 x 24 | 8.00 | 2750 | 22,000 | |

The stack flow is 86,500 CFM, the sum of #3, #4, #5 and #9

1.c Company data for gel and barrier coating areas exhaust flow

Gel coat 17" exhaust duct data. Area = 1.6 $ft^2$ (date unknown)

| DATA point | HORIZ FPM | VERT-TOP FPM | VERT- BTM FPM | HORIZ-RT FPM | HORIZ-TOP FPM | VERT-BTM FPM |
|---|---|---|---|---|---|---|
| 1/2" | 1850 | 2100 | 1950 | 1850 | 2150 | 2150 |
| 1 3/8" | 1950 | 2300 | 2100 | 2300 | 2250 | 2200 |
| 2 1/2" | 2150 | 2350 | 2250 | 2300 | 2400 | 2300 |
| 3 7/8" | 2200 | 2500 | 2350 | 2600 | 2600 | 2250 |
| 5 3/4" | 2200 | 2500 | 2400 | 2600 | 2650 | 2450 |
| 11 1/4" | 2250 | 2550 | 2500 | 2600 | 2550 | 2750 |
| Summation | 12,600 | 14,300 | 11,600 | 14,250 | 14,600 | 14,100 |
| Average FPM | 2100 | 2380 | 1930 | 2380 | 2430 | 2350 |
| Overall average | | 2140 FPM | | | 2390 FPM | |
| Flow | | 3420 CFM | | | 3820 CFM | |

1.d Company flow data for barrier coat area (date unknown)

Exhaust duct is 13" diameter; area is 0.9127 $ft^2$

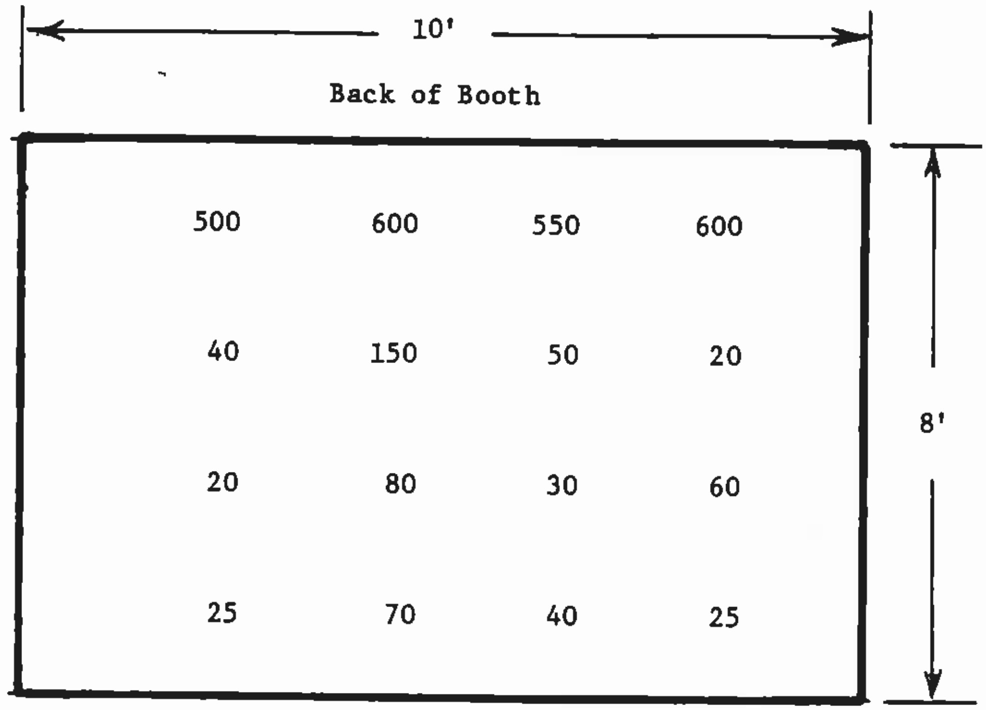
| | Data set I | | Data set II | |
|---|---|---|---|---|
| Data Point | Horizontal FPM | Vertical FPM | Horizontal FPM | Vertical FPM |
| 3/8" | 1900 | 1800 | 1900 | 1750 |
| 1" | 2100 | 2350 | 2100 | 2050 |
| 1 7/8" | 2250 | 2100 | 2200 | 2100 |
| 2 7/8" | 2300 | 2200 | 2300 | 2300 |
| 4 1/2" | 2300 | 2300 | 2250 | 2250 |
| 8 1/2" | 2230 | 2300 | 2200 | 2300 |
| 10 1/8" | 2300 | 2300 | 2250 | 2250 |
| 11 1/8" | 2300 | 2150 | 2250 | 2200 |
| 12 " | 2310 | 2100 | 2200 | 2100 |
| 12 5/8" | 2350 | 2050 | 2300 | 2100 |
| Summation | 22,340 | 21,650 | 21,950 | 21,400 |
| Average FPM | 2230 | 2170 | 2200 | 2140 |
| Flow CFM | 2040 | 1980 | 2000 | 1950 |
| Average CFM | 2010 | | 1980 | |

1.e Company flow data for make-up air to gel and barrier coat areas

Make-up air duct is 20" diameter; area = 2.182 $ft^2$ (date unknown)

| | DATA SET I | | | DATA SET II | | |
|---|---|---|---|---|---|---|
| Data Point | Horiz. FPM | Horiz. FPM | Vert. FPM | Horiz. FPM | Horiz. FPM | Vert. FPM |
| 5/8" | 2200 | 2600 | 2600 | 2250 | 2500 | 2100 |
| 1 3/4" | 2250 | 2600 | 2850 | 2350 | 2550 | 2400 |
| 3 1/4 | 2800 | 2500 | 2850 | 2700 | 2700 | 2400 |
| 5" | 2600 | 2600 | 2850 | 2600 | 2750 | 2300 |
| 7 1/4" | 2700 | 2600 | 2650 | 2800 | 2850 | 2100 |
| 12" | 2700 | 2550 | 2600 | 2850 | - | 2100 |
| Summation | 15,250 | 15,500 | 16,400 | 15,550 | 13,350 | 13,400 |
| Average | 2540 | 2580 | 2730 | 2590 | 2670 | 2230 |
| Velocity | | 2620 FPM | | | 2460 FPM | |
| Flow | | 5720 CFM | | | 5450 CFM | |

1.f Grinder booth air flow, 6-9-83




Front of booth

Open area of floor grid is 63%. This was based on a 16 1/2" by 5 1/2" area having 16 openings 3 1/2" by 1' in size.

The average velocity in the floor grid of the booth was 180 FPM in a total open area of 50 $ft^2$ ($80ft^2$ x .63).

The total flow is then 9000 CFM.

6. Traverse of supply air duct to Lamination #1 area, 6-9-83
24 point traverse, duct size is 48" x 40"

48"

Top of duct

40"

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1750 | 1650 | 1725 | 1700 | 1700 | 1400 | 1450 | 1400 |
| 1800 | 1700 | 1600 | 1675 | 1650 | 1550 | 1650 | 1500 |
| 1600 | 1550 | 1600 | 1625 | 1500 | 1500 | 1550 | 1450 |

Average velocity is 1600 FPM
Total flow to Lamination #1 area is 21,200 CFM

7. Lamination #2 air supply duct, 6-9-83
Twenty seven point traverse, duct is 56" x 34" (13.2 $ft^2$)

56"

Top of duct

34"

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 900 | 1050 | 1100 | 1150 | 1200 | 1150 | 1250 | 1250 | 1150 |
| 900 | 1050 | 1100 | 1100 | 1200 | 1150 | 1250 | 1250 | 1200 |
| 850 | 1000 | 950 | 1100 | 1150 | 975 | 1150 | 1200 | 1100 |

Average velocity is 1100 FPM
The total flow to Lamination #2 area is 14,600 CFM

8. Roof ductwork, Traverse point 2, 6-9-83
20 Point traverse, duct size is 48" x 31" ($10.33\ ft^2$)

48"
Top of duct

| | | | | |
|---|---|---|---|---|
| 2050 | 2000 | 2100 | 2100 | 1800 |
| 2200 | 2000 | 2400 | 2500 | 2100 |
| 2200 | 2350 | 2700 | 2900 | 2500 |
| 2800 | 3000 | 3100 | 2800 | 2500 |

31"

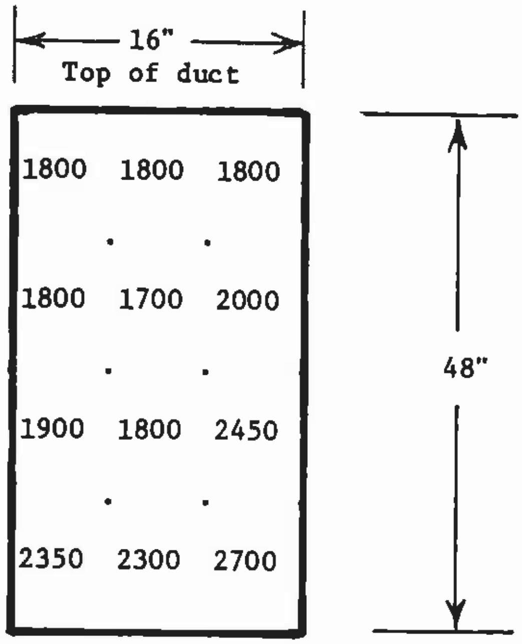
Average velocity in duct is 2400 FPM

Total flow in duct is 24,900 CFM

9. Roof ducting, Traverse point #4, 6-9-83
Duct size is 12" x 10"

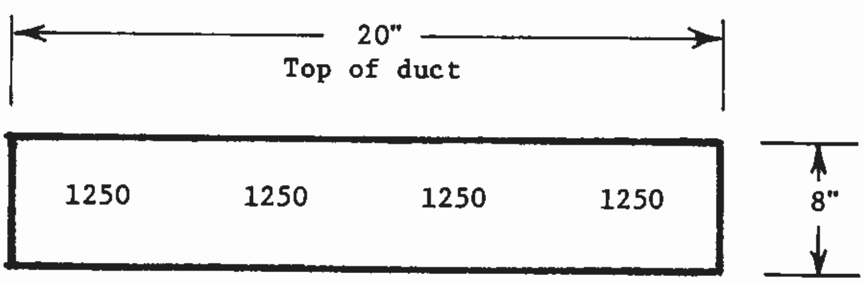
No flow was observed in this duct. It was found to be clogged with debris.

10. Roof ducting - Traverse point #5, 6-9-83
12 point traverse, duct size is 48" x 16" (5.333 $ft^2$)




Average velocity in duct is 2030 FPM
Total flow in duct is 10,800 CFM

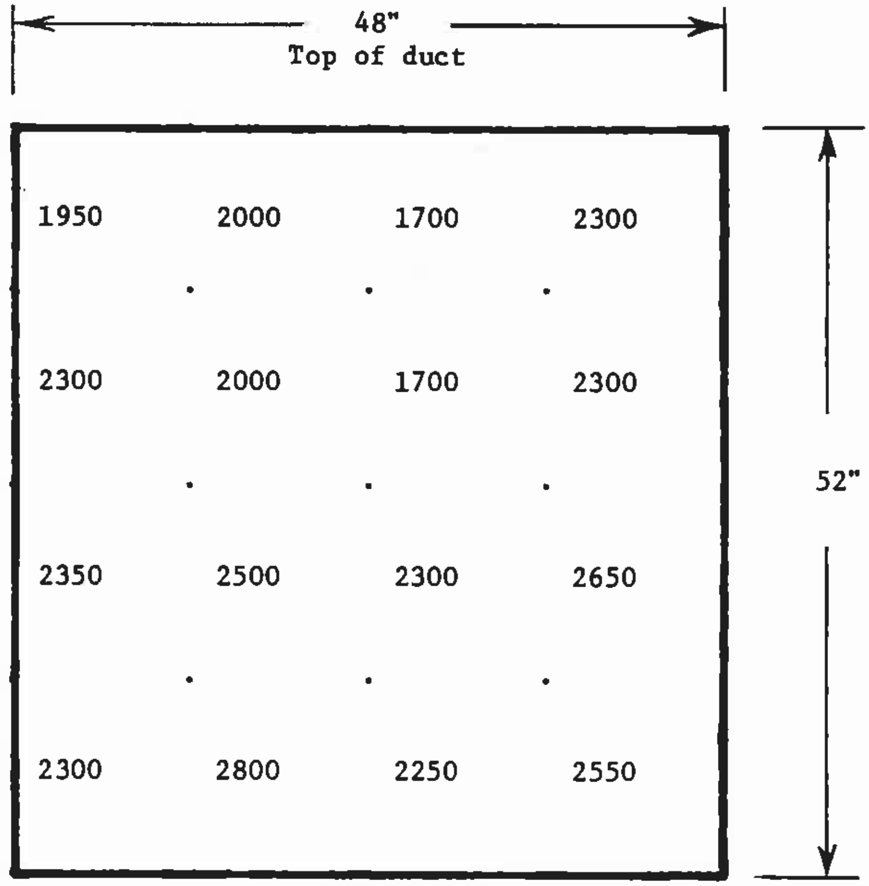
11. Traverse point #7, 6-9-83
Velocity traverse is duct 20" x 8" (1.11 $ft^2$)




Average velocity is 1250 FPM
Total flow is 3330 CFM

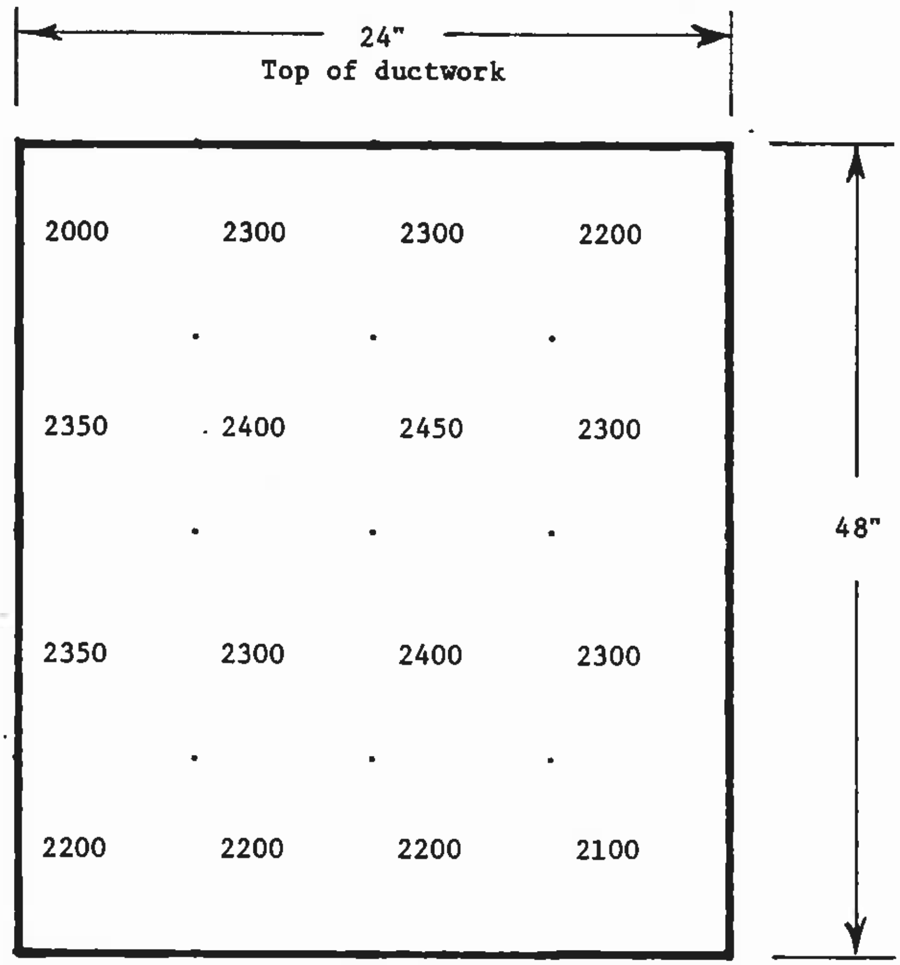
Note: we did not measure this flow in the duct, we used the data written on the duct work by the ventilation contractor.

12. Roof ducting - Traverse point #8, 6-9-83
16 point traverse, duct size is 48" x 52" (17.333 $ft^{23}$)




Average velocity in duct is 2300 FPM
Total flow in duct is 39,900 CFM

13. Roof ducting - Traverse point #9, 6-9-83
16 point traverse, duct size is 24" x 48" (8 $ft^2$)




Average velocity is 2270 FPM
Total flow is 18,200 CFM

14. Velocity traverse of 13" diameter duct (0.9128 $ft^2$), 6-8-83
10 point traverse (20 loci) of barrier coat exhaust duct

| Data Point | Vertical FPM | Horizontal FPM |
|---|---|---|
| 3/8" | 1700 | 1850 |
| 1" | 1550 | 1725 |
| 1 7/8" | 1800 | 1850 |
| 2 7/8" | 1875 | 1950 |
| 4 1/2" | 1975 | 1950 |
| 8 1/2" | 2025 | 1925 |
| 10 1/2" | 2050 | 1950 |
| 11 1/8" | 2050 | 1975 |
| 12" | 2050 | 2025 |
| 12 5/8" | 2050 | 1950 |
| Sum | 19,125 | 19,150 |
| Average | 1910 | 1920 |
| | 1915 FPM | |

Total flow is 1750 CFM

Velocity traverse of 17" diameter duct (1.576 $ft^2$) 6-8-83
10 point traverse (20 loci) of Gel coat exhaust duct with TSI Velometer

| Data Point | Vertical FPM | Horizontal FPM |
|---|---|---|
| 1/2" | 1000 | 1950 |
| 1 3/8" | 1650 | 1975 |
| 2 1/2" | 2125 | 2200 |
| 3 7/8" | 2250 | 2300 |
| 5 3/4" | 2400 | 2300 |
| 11 1/4" | 2350 | 2275 |
| 13 1/8" | 2350 | 2275 |
| 14 1/2" | 2200 | 2275 |
| 15 7/8 | 2300 | 2300 |
| 16 1/2" | 1975 | 2100 |
| Sum | 20,600 | 21,975 |
| Average | 2060 | 2200 |
| | 2130 FPM | |

Total flow is 3360 CFM

Appendix A-2 Personal and area sampling results for Plant A

1a. Personal sampling data, lamination, gel coat and barrier coat workers[a].

| EMPLOYEE | DAY | SAMPLE TIME Minutes | SAMPLE VOLUME Liters | STYRENE ppm |
|---|---|---|---|---|
| A | 1 | 93 | 0.99 | 59 |
| A | 1 | 181 | 1.09 | 106 |
| B | 1 | 93 | 0.99 | 57 |
| B | 1 | 181 | 1.90 | 181 |
| C | 1 | 87 | 1.40 | 149 |
| C | 1 | 182 | 3.40 | 154 |
| D | 1 | 80 | 0.77 | 37 |
| D | 1 | 185 | 1.74 | 38 |
| E | 1 | 78 | 0.64 | 33 |
| E | 1 | 185 | 1.47 | 62 |
| F | 1 | 73 | 0.74 | 70 |
| F | 1 | 185 | 1.86 | 56 |
| G | 1 | 71 | 0.80 | 59 |
| G | 1 | 185 | 1.98 | 47 |
| H | 1 | 69 | 0.82 | 57 |
| H | 1 | 186 | 2.13 | 63 |
| I | 1 | 82 | 0.82 | 52 |
| I | 1 | 185 | 1.92 | 49 |
| A | 2 | 215 | 2.21 | 78 |
| A | 2 | 184 | 1.90 | 106 |
| B | 2 | 215 | 2.20 | 84 |
| B | 2 | 184 | 1.89 | 86 |
| C | 2 | 217 | 3.47 | 169 |
| C | 2 | 183 | 2.89 | 203 |
| D | 2 | 222 | 2.15 | 32 |
| D | 2 | 195 | 1.85 | 56 |
| E | 2 | 221 | 1.82 | 58 |
| E | 2 | 193 | 1.45 | 73 |
| F | 2 | 225 | 2.25 | 70 |
| F | 2 | 190 | 1.95 | 47 |
| G | 2 | 223 | 2.44 | 45 |
| G | 2 | 190 | 2.10 | 51 |
| H | 2 | 224 | 2.63 | 51 |
| H | 2 | 190 | 2.23 | 34 |
| I | 2 | 223 | 2.29 | 41 |
| I | 2 | 185 | 1.96 | 53 |

Appendix A-2. 1a. Personal sampling data - Plant A (continued).

| EMPLOYEE | DAY | SAMPLE TIME Minutes | SAMPLE VOLUME Liters | STYRENE ppm |
|---|---|---|---|---|
| A | 3 | 223 | 2.26 | 89 |
| A | 3 | 187 | 1.91 | 84 |
| B | 3 | 224 | 2.33 | 76 |
| B | 3 | 187 | 1.95 | 78 |
| C | 3 | 225 | 3.50 | 161 |
| C | 3 | 185 | 2.83 | 83 |
| D | 3 | 222 | 2.14 | 29 |
| D | 3 | 184 | 1.81 | b |
| E | 3 | 223 | 1.86 | LT 1.25[c] |
| E | 3 | 191 | 1.41 | 72 |
| F | 3 | 228 | 2.23 | 49 |
| F | 3 | 194 | 1.93 | 54 |
| G | 3 | 224 | 2.41 | 44 |
| G | 3 | 194 | 2.04 | 54 |
| H | 3 | 224 | 2.58 | 43 |
| H | 3 | 194 | 2.19 | 45 |
| I | 3 | 224 | 2.43 | 60 |
| I | 3 | 191 | 2.08 | 58 |

a. Data was obtained with MDA Accuhaler pumps and charcoal sampling tubes.
b. Sample lost in analysis
c. Result considered as outlier; no reason for low value

1b. Personal sampling data, grinder booth worker.

| EMPLOYEE | DAY | SAMPLE TIME MINUTES | SAMPLE VOLUME LITERS | DUST $mg/m^3$ |
|---|---|---|---|---|
| J | 1 | 79 | 119 | 12 |
| J | 1 | 209 | 314 | 46 |
| K | 2 | 82 | 117 | 6.5 |
| K | 2 | 73 | 110 | 7.5 |
| K | 2 | 59 | 89 | 4.6 |
| K | 2 | 74 | 111 | 11.7 |
| K | 2 | 55 | 83 | 11.3 |
| K | 2 | 60 | 90 | 5.4 |
| K | 3 | 86 | 129 | 3.41 |
| K | 3 | 53 | 80 | 4.38 |
| K | 3 | 65 | 98 | 5.5 |
| K | 3 | 88 | 132 | 10.83 |
| K | 3 | 77 | 116 | 5.86 |

Data was obtained with DuPont P2500 pumps and 5 micron PVC membrane filters.

Appendix A-2. (Cont.)

2.a Area sampling data, grinder booth make-up air dust concentration.[a]

| DAY | SAMPLE TIME MINUTES | SAMPLE VOLUME LITERS | DUST $mg/m^3$ |
|---|---|---|---|
| 3 | 239 | 359 | 4.3 |
| 3 | 186 | 279 | 10.2 |

a. Data obtained with DuPont P2500 pumps and PVC 5 micron filters.

2.b. Area sampling data, gelcoat and barrier coat areas.[a]

| DAY | LOCATION | SAMPLE TIME Minutes | SAMPLE VOLUME Liters | STYRENE ppm |
|---|---|---|---|---|
| 1 | Gel coat area | 77 | 3.81 | 49 |
| 1 | " | 220 | 10.9 | 62 |
| 1 | Barrier coat area | 73 | 3.64 | 123 |
| 1 | " | 218 | 10.9 | 80 |
| 2 | Gel coat area | 231 | 11.4 | 66 |
| 2 | " | 223 | 11.0 | 64 |
| 2 | Barrier coat area | 231 | 11.5 | 192 |
| 2 | " | 226 | 11.3 | 249 |
| 3 | Gel coat area | 250 | 12.4 | 61 |
| 3 | " | 206 | 10.2 | 58 |
| 3 | Barrier coat area | 256 | 9.1 | 167 |
| 3 | " | 202 | 9.4 | 218 |

a. Data obtained with MDA Accuhaler pumps and charcoal sampling tubes.

Appendix B-1 Ventilation data for Plant B

1.a. Plant B-Exhaust Duct Velocities and Flows for Lamination Booths, 9-13-83

All velocities were obtained with TSI Velometer, Model 1650, and are expressed in feet per minute (FPM)

Booth #1, Duct size 42" x 20" (area = 5.8 $ft^2$)

WIDTH, 42 inches

DEPTH 20 inches

| | | | | |
|---|---|---|---|---|
| 3500 | 3300 | 3000 | 1500 | 2600 |
| 3800 | 3500 | 3200 | 2500 | 2800 |
| 3500 | 3600 | 3100 | 2800 | 3100 |
| 900 | 2200 | 3200 | 3100 | 2000 |

Average velocity = 2860 FPM, Flow = 16,680 CFM

Booth #2, Duct size 50" x 18" (area = 6.2 $ft^2$)

WIDTH, 50 inches

DEPTH 18 inches

| | | | | |
|---|---|---|---|---|
| 2500 | 2500 | 2500 | 2800 | 3200 |
| 2800 | 2900 | 2600 | 2400 | 3100 |
| 3000 | 2900 | 2700 | 2600 | 2900 |

Average velocity = 2760 FPM, Flow = 17,250 CFM

Booth #3, Duct size 62" x 20" (area = 6.2 $ft^2$)

WIDTH, 62 inches

DEPTH 20 inches

| | | | | |
|---|---|---|---|---|
| 2800 | 2700 | 2900 | 2700 | 2400 |
| 2800 | 2700 | 2800 | 2600 | 2500 |
| 2900 | 2700 | 2500 | 2500 | 2500 |

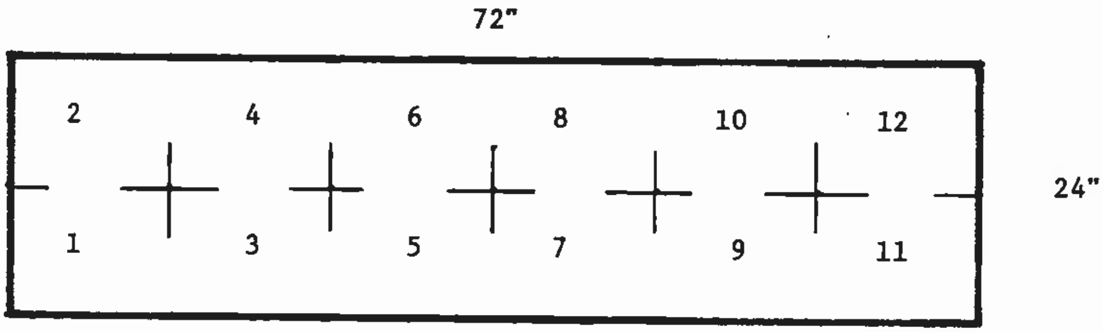
Average velocity = 2670 FPM, Flow = 16,650 CFM

Total flow for booths #1. #2, and #3 = 50,580 CFM

Appendix B-1 (Cont.)

1.b. PLANT B-Air supply to small parts room near booths #1 and #2, 9-13-83

Velocity traverse by pitot tube and TSI hot wire velometer Model 1600




| | PITOT TUBE | | TSI |
|---|---|---|---|
| DATA POINT | VP in. $H_2O$ | VELOCITY FPM | VELOCITY FPM |
| 1 | 0.30 | 2,195 | 2,500 |
| 2 | 0.36 | 2,405 | 2,550 |
| 3 | 0.37 | 2,435 | 2,650 |
| 4 | 0.39 | 2,500 | 2,550 |
| 5 | 0.35 | 2,370 | 2,450 |
| 6 | 0.29 | 2,160 | 2,400 |
| 7 | 0.31 | 2,230 | 2,400 |
| 8 | 0.34 | 2,335 | 2,450 |
| 9 | 0.30 | 2,195 | 2,300 |
| 10 | 0.36 | 2,405 | 2,500 |
| 11 | 0.24 | 1,960 | 2,100 |
| 12 | 0.33 | 2,300 | 2,500 |

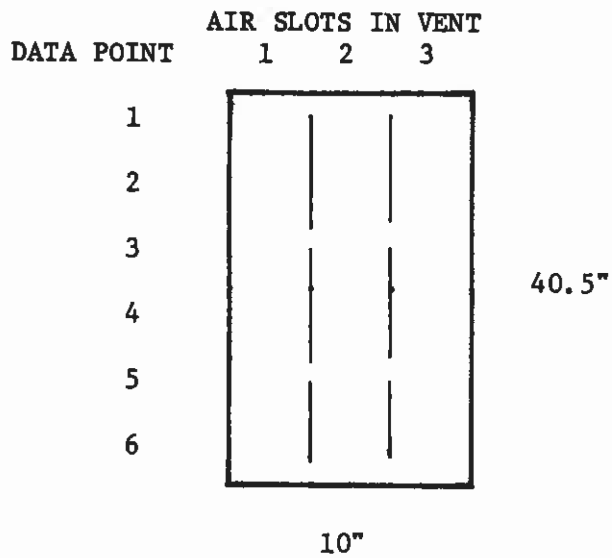
| | Pitot tube | TSI |
|---|---|---|
| Total velocity, FPM | 27,490 | 29,350 |
| Average velocity, FPM | 2,290 | 2,445 |
| Flow, CFM | 27,480 | 29,340 (Duct area = 12 $ft^2$) |

Average flow, CFM = 28,410

Appendix B-1 (Cont.)

1.c. Plant B-Air supply to small parts area wall vent, 9-13-83

This duct passes through the wall then turns right and exits immediately through louvered outlet.




Note: The width of the vertical air slots varies from 3.25" to 4" and results in different data point areas.

| DATA POINT | VELOCITY IN SLOT, FPM 1 | 2 | 3 | AVG. VEL. | AREA $ft^2$ | FLOW CFM |
|---|---|---|---|---|---|---|
| 1 | 700 | 1750 | 500 | 983 | 0.474 | 466 |
| 2 | 950 | 600 | 1150 | 1417 | 0.542 | 768 |
| 3 | 1950 | 2100 | 2000 | 2017 | 0.440 | 887 |
| 4 | 1000 | 1300 | 1000 | 1100 | 0.510 | 561 |
| 5 | 400 | 360 | 1400 | 720 | 0.583 | 420 |
| 6 | 340 | 700 | 1650 | 897 | 0.474 | 425 |
| | | | | | | Total CFM = 3,527 |

Appendix B-2 Personal and area sampling data for Plant B.

1.a. Personal and area sampling data - Plant B Worker A, Group Leader, Small Parts

| DATE | SAMPLE NUMBER | TIME Min. | VOLUME Liters | mg | STYRENE mg/m$^3$ | ppm |
|---|---|---|---|---|---|---|
| 9/13 | 073 | 234 | 6.8 | 0.24 | 35.29 | 8 |
| 9/13 | 083 | 316 | 9.2 | 0.26 | 28.26 | 7 |
| 9/15 | 159 | 204 | 4.5 | 0.30 | 66.67 | 16 |
| 9/15 | 151 | 251 | 5.3 | 0.24 | 45.28 | 11 |
| 9/14 | 095 | 34 | 3.5 | 0.34 | 97.14 | 23 |
| " | 096 | 24 | 2.7 | 0.19 | 70.37 | 17 |
| " | 112 | 31 | 3.0 | 0.81 | 270.00 | 63 |
| " | 113 | 32 | 3.5 | 0.43 | 122.86 | 29 |
| " | 084 | 32 | 3.0 | 0.23 | 76.67 | 18 |
| " | 074 | 27 | 2.9 | 0.46 | 158.62 | 37 |
| " | 110 | 29 | 2.8 | 0.40 | 142.86 | 34 |
| " | 107 | 32 | 3.5 | 0.12 | 34.29 | 8 |
| " | 103 | 28 | 3.1 | 0.07 | 22.58 | 5 |
| " | 127 | 31 | 3.4 | 0.05 | 14.71 | 3 |
| " | 122 | 32 | 2.7 | 0.02 | 7.41 | 2 |
| " | 125 | 32 | 3.3 | 0.05 | 15.15 | 4 |
| " | 135 | 30 | 3.3 | 0.08 | 24.24 | 6 |
| " | 134 | 30 | 3.4 | 0.05 | 14.71 | 3 |
| " | 137 | 32 | 3.6 | 0.47 | 130.56 | 31 |
| " | 145 | 25 | 2.5 | 0.13 | 52.00 | 12 |
| Sum of 9/14 data | | 481 | 50.2 | 3.90 | 77.69 | 18 |

Appendix B-2 (cont)

1.b. Plant B-Personal Samples, Worker B, Small Parts Laminator

| DATE | SAMPLE NUMBER | TIME Min. | VOLUME Liters | STYRENE mg | mg/m$^3$ | ppm |
|---|---|---|---|---|---|---|
| 9/13 | 087 | 314 | 6.3 | 0.83 | 131.75 | 31 |
| 9/13 | 075 | 234 | 4.9 | 0.86 | 175.51 | 41 |
| 9/15 | 157 | 209 | 0.8 | 0.22 | 275.00 | 65 |
| 9/15 | 160 | 251 | 1.3 | 0.33 | 253.85 | 60 |
| 9/14 | 094 | 27 | 2.5 | 0.06 | 24.00 | 06 |
| " | 100 | 31 | 2.6 | 1.50 | 576.92 | 136 |
| " | 119 | 29 | 2.2 | 0.61 | 277.27 | 65 |
| " | 114 | 31 | 2.5 | 0.37 | 148.00 | 35 |
| " | 086 | 30 | 1.6 | 0.13 | 81.25 | 19 |
| " | 082 | 27 | 2.4 | 0.19 | 79.17 | 19 |
| " | 104 | 25 | 2.0 | 0.90 | 450.00 | 106 |
| " | 105 | 25 | 2.2 | 0.95 | 431.82 | 102 |
| " | 115 | 28 | 0.1 | 0.01 | 100.00 | 24 |
| " | 109 | 16 | 1.7 | 0.01 | 5.88 | 1 |
| " | 131 | 29 | 2.8 | 0.74 | 264.29 | 62 |
| " | 129 | 31 | 3.2 | 0.42 | 131.25 | 31 |
| " | 141 | 31 | 3.0 | 0.21 | 70.00 | 16 |
| " | 138 | 33 | 3.2 | 0.07 | 21.88 | 5 |
| " | 140 | 30 | 2.4 | 0.23 | 95.83 | 23 |
| " | 142 | 28 | 2.7 | 0.16 | 59.26 | 14 |
| Sum of 9/14 data | | 451 | 37.1 | 6.56 | 176.82 | 42 |

Appendix B-2 (Cont.)

1.c. Plant B-Personal Samples, Worker C, Small Parts Laminator

| DATE | SAMPLE NUMBER | TIME Min. | VOLUME Liters | STYRENE mg | STYRENE $mg/m^3$ | STYRENE ppm |
|---|---|---|---|---|---|---|
| 9/13 | 079 | 235 | 4.9 | 0.28 | 57.14 | 13 |
| 9/15 | 153 | 250 | 5.1 | 0.75 | 147.00 | 35 |
| 9/14 | 093 | 29 | 2.8 | 0.19 | 67.86 | 16 |
| " | 092 | 28 | 2.9 | 0.56 | 193.10 | 45 |
| " | 121 | 28 | 2.7 | 0.25 | 92.59 | 22 |
| " | 120 | 30 | 3.0 | 0.37 | 123.33 | 30 |
| " | 081 | 28 | 3.1 | 0.56 | 180.65 | 42 |
| " | 116 | 30 | 2.6 | 0.15 | 57.69 | 14 |
| " | 106 | 27 | 2.6 | 0.46 | 176.92 | 42 |
| " | 102 | 30 | 3.1 | 0.62 | 200.00 | 47 |
| " | 108 | 28 | 2.7 | 0.16 | 59.26 | 14 |
| " | 123 | 29 | 2.9 | 0.03 | 10.34 | 2 |
| " | 128 | 31 | 3.0 | 0.11 | 36.67 | 9 |
| " | 139 | 32 | 3.4 | 0.12 | 35.29 | 8 |
| " | 133 | 30 | 3.0 | 0.04 | 13.33 | 3 |
| " | 136 | 31 | 3.1 | 0.03 | 9.68 | 2 |
| " | 111 | 27 | 2.6 | 0.32 | 123.08 | 29 |
| " | 150 | 28 | 2.8 | 0.38 | 135.71 | 32 |
| Sum of 9/14 data | | 466 | 46.3 | 4.35 | 93.95 | 22 |

Appendix B-2 (Cont.)

1.d. Plant B-Personal Samples, Worker D, Tank Laminator

| DATE | SAMPLE NUMBER | TIME Min. | VOLUME Liters | STYRENE mg | STYRENE mg/m$^3$ | STYRENE ppm |
|---|---|---|---|---|---|---|
| 9/13 | 072 | 234 | 5.1 | 0.26 | 50.94 | 12 |
| 9/14 | 099 | 217 | 4.6 | 0.26 | 56.52 | 13 |
| 9/14 | 124 | 254 | 5.3 | 0.33 | 62.26 | 15 |
| 9/15 | 155 | 207 | 4.3 | 0.33 | 76.74 | 18 |
| 9/15 | 161 | 252 | 5.5 | 0.36 | 65.45 | 15 |

Personal Sample Data - Plant B.
Worker E, Gel Coater, Small Parts

| DATE | SAMPLE NUMBER | TIME Min. | VOLUME Liters | STYRENE mg | STYRENE mg/m$^3$ | STYRENE ppm |
|---|---|---|---|---|---|---|
| 9/13 | 080 | 26 | 2.8 | 0.89 | 312.86 | 74 |
| 9/14 | 097 | 27 | 2.7 | 0.72 | 266.67 | 63 |

Appendix B-2 (Cont.)

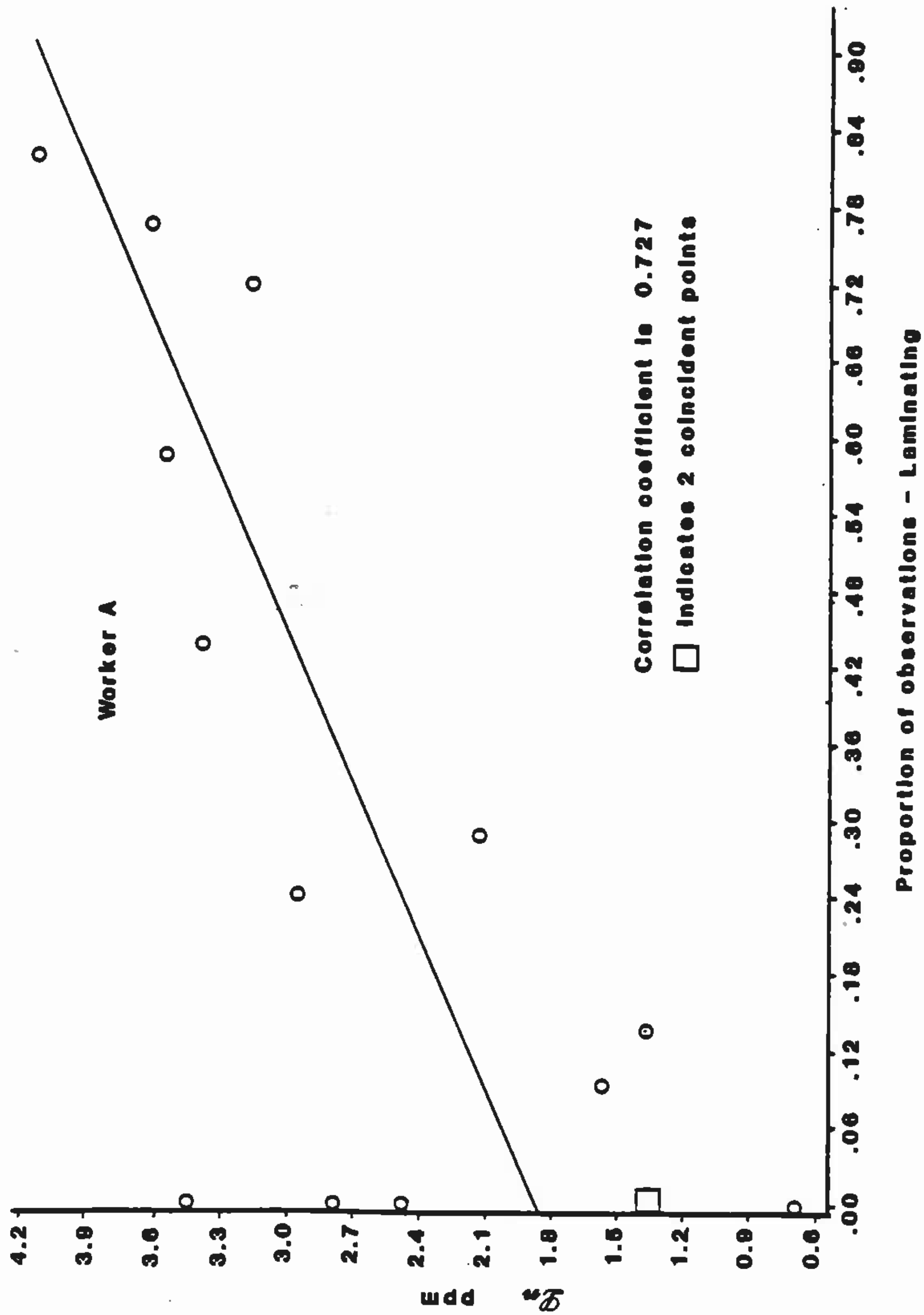
1.e. Plant B-Area Samples

| DATE | SAMPLE NUMBER | LOCATION | TIME Min. | VOLUME Liters | STYRENE mg | mg/$m^3$ | ppm |
|---|---|---|---|---|---|---|---|
| 9/13 | 078 | Betw'n small prts. & hull lay-up[1] | 252 | 2.8 | 0.24 | 85.71 | 20 |
| 9/13 | 088 | " | 351 | 2.5 | 0.12 | 48.00 | 11 |
| 9/13 | 076 | On column in small | 6.8 | 0.29 | 42.65 | | 10 |
| 9/13 | 085 | parts room[2] | 354 | 9.2 | 0.20 | 21.74 | 5 |
| 9/14 | 098 | See foot note 1. | 252 | 5.0 | 0.03 | 6.00 | 1 |
| 9/14 | 126 | " | 335 | 6.4 | 0.02 | 3.13 | 1 |
| 9/14 | 101 | See footnote 2. | 256 | 6.9 | 0.22 | 31.88 | 7 |
| 9/14 | 130 | " | 332 | 9.0 | 0.10 | 11.11 | 3 |
| 9/15 | 156 | See footnote 1. | 215 | 4.3 | 0.05 | 11.63 | 3 |
| 9/15 | 152 | " | 330 | 6.6 | 0.27 | 40.91 | 10 |
| 9/15 | 158 | See footnote 2. | 214 | 5.8 | 0.17 | 29.31 | 7 |
| 9/15 | 144 | " | 331 | 8.9 | 0.22 | 24.72 | 6 |

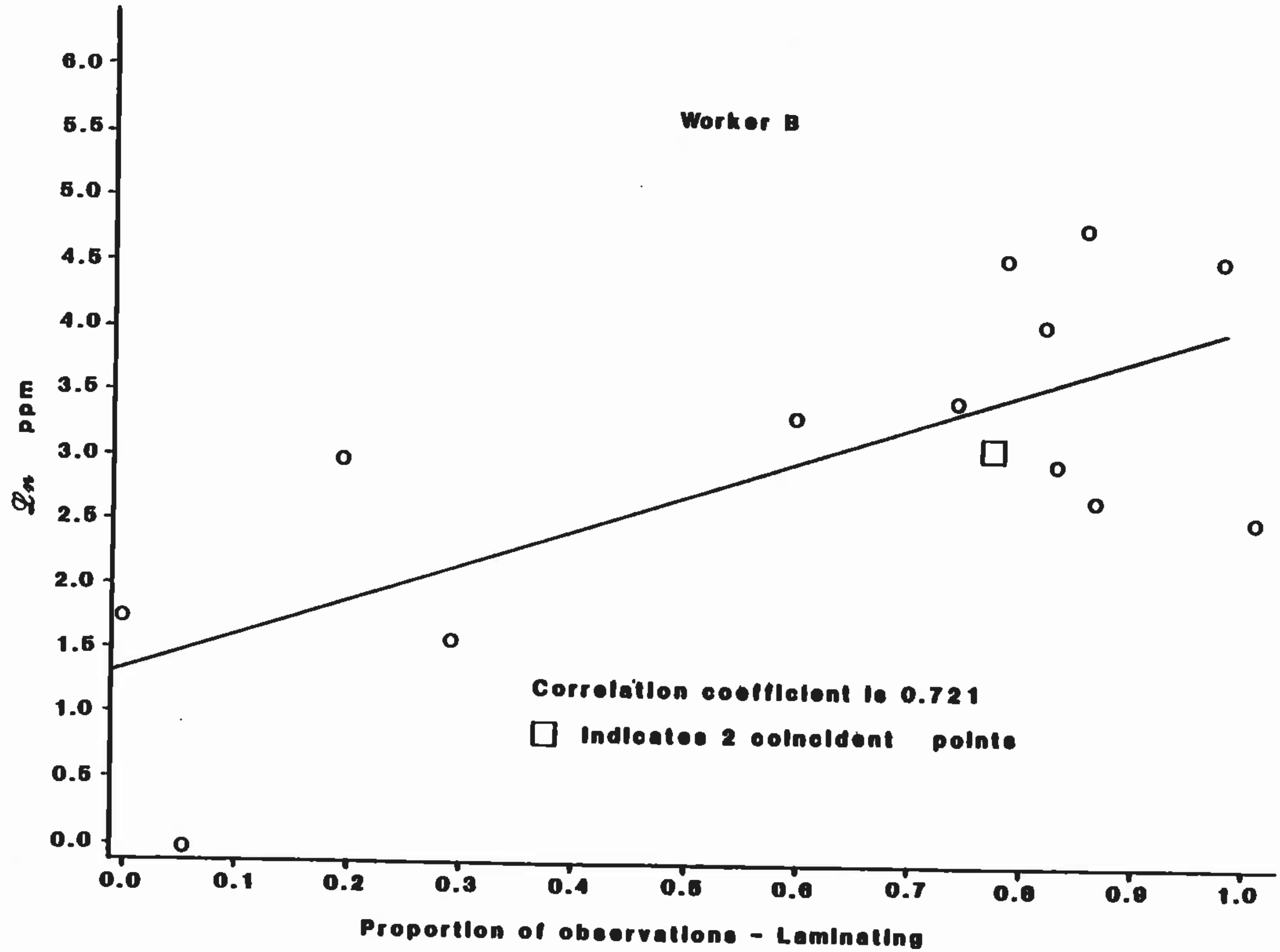
1. Sample site located in doorway by booth #2 between small parts area and the hull lamination area. See Figure 1. for location.
2. Sample site is located in small parts area on column between booths #1 and #2. See Figure 1. for location.

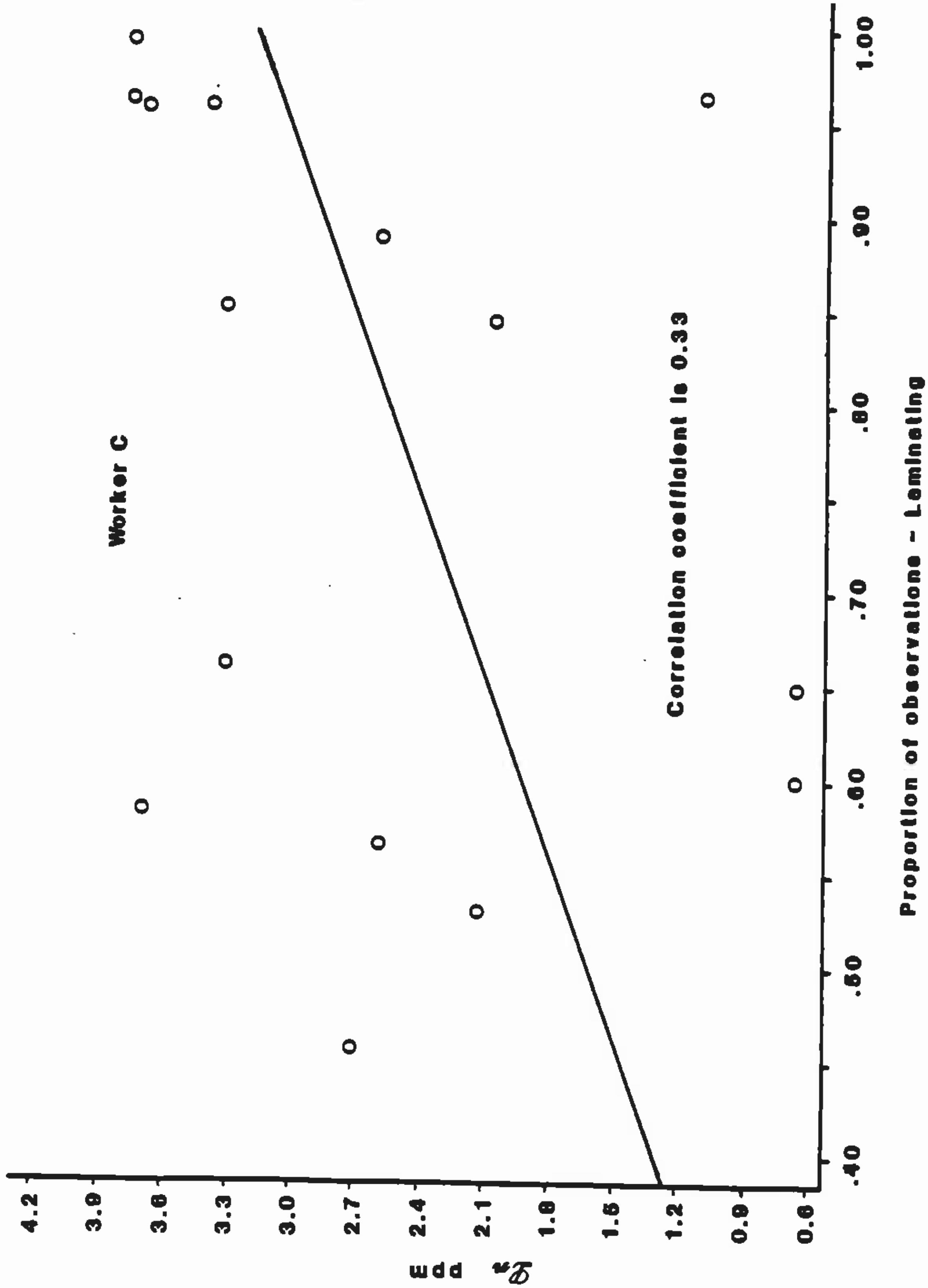
Appendix C.

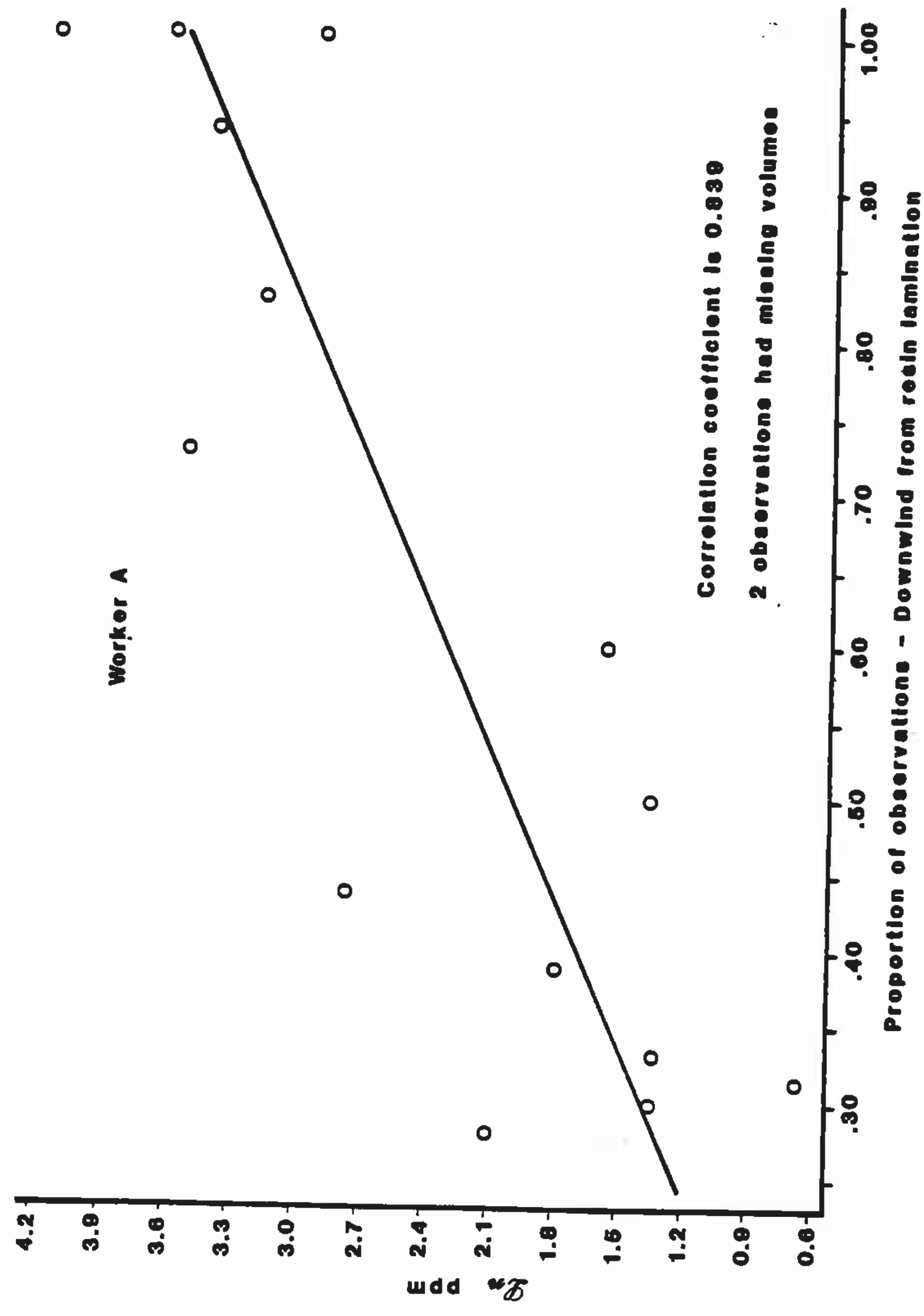
Linear regression analysis of work practices for Plant B.



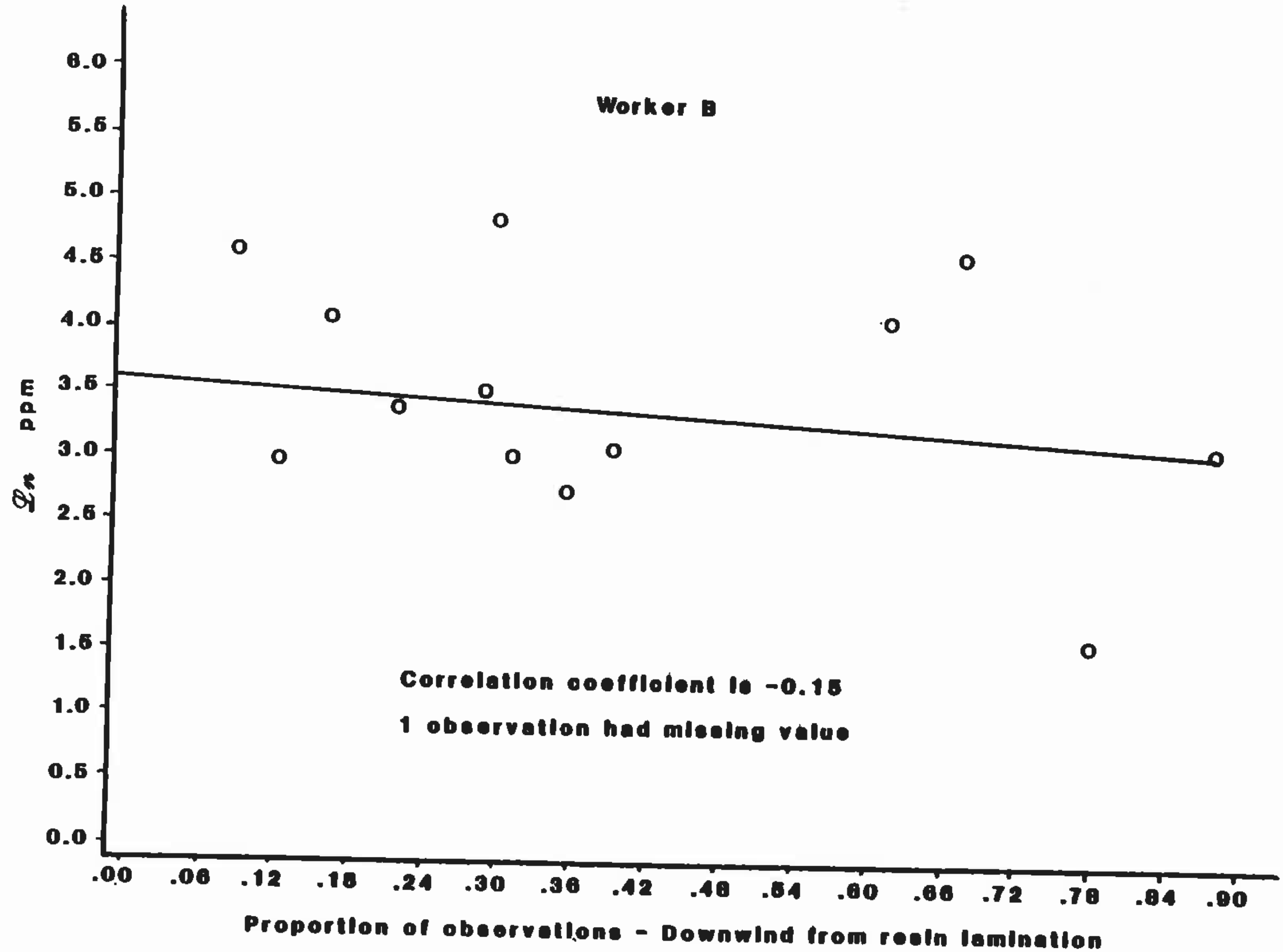
Worker A
Correlation coefficient is 0.727
Indicates 2 coincident points
Proportion of observations - Laminating
ppm
.00 .06 .12 .18 .24 .30 .36 .42 .48 .54 .60 .66 .72 .78 .84 .90
0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3 3.6 3.9 4.2


Worker B
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm
Correlation coefficient is 0.721
Indicates 2 coincident points
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Proportion of observations - Laminating

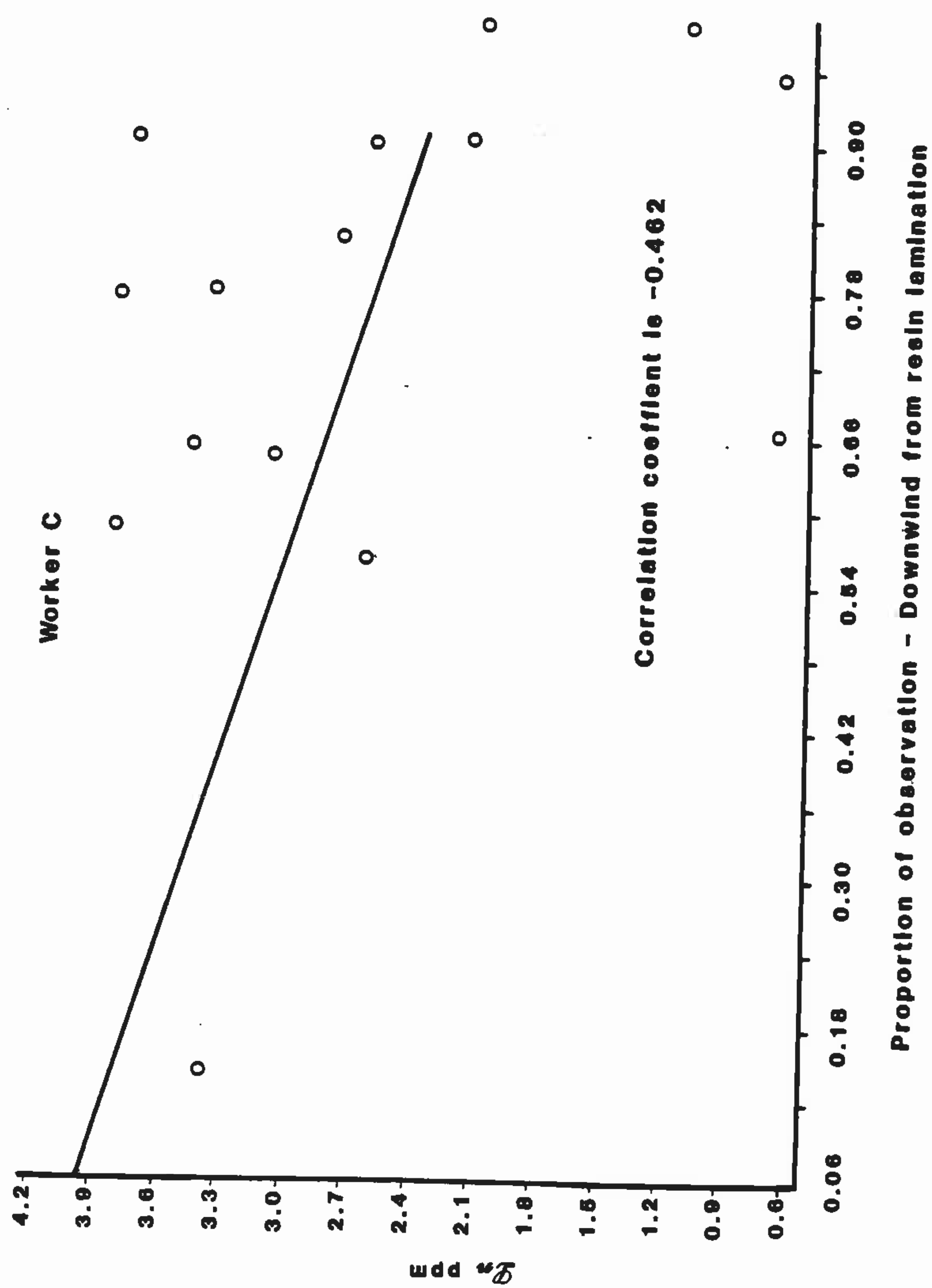

Worker C
Correlation coefficient is 0.33
Proportion of observations - Laminating
ppm
4.2
3.9
3.6
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
.40
.50
.60
.70
.80
.90
1.00

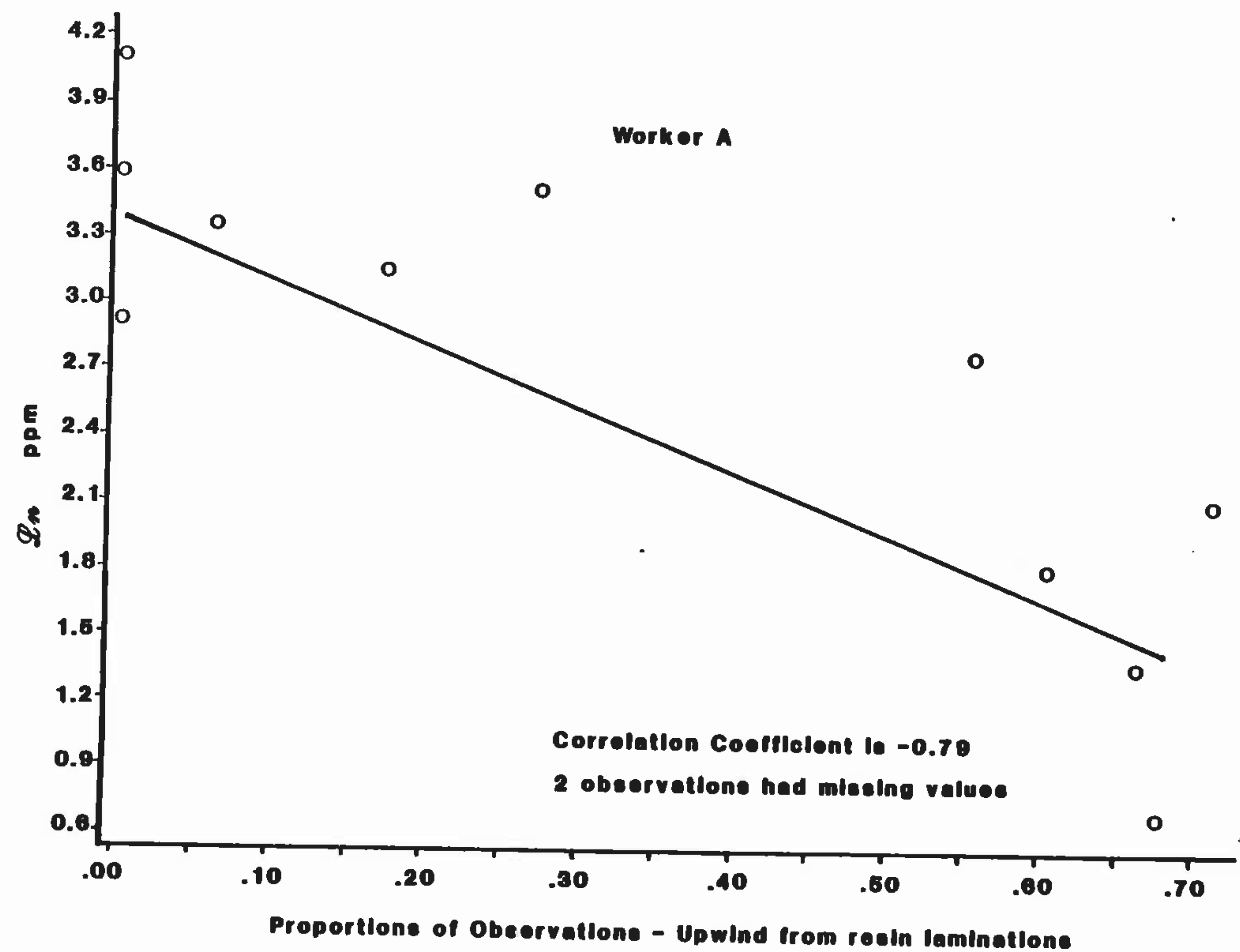


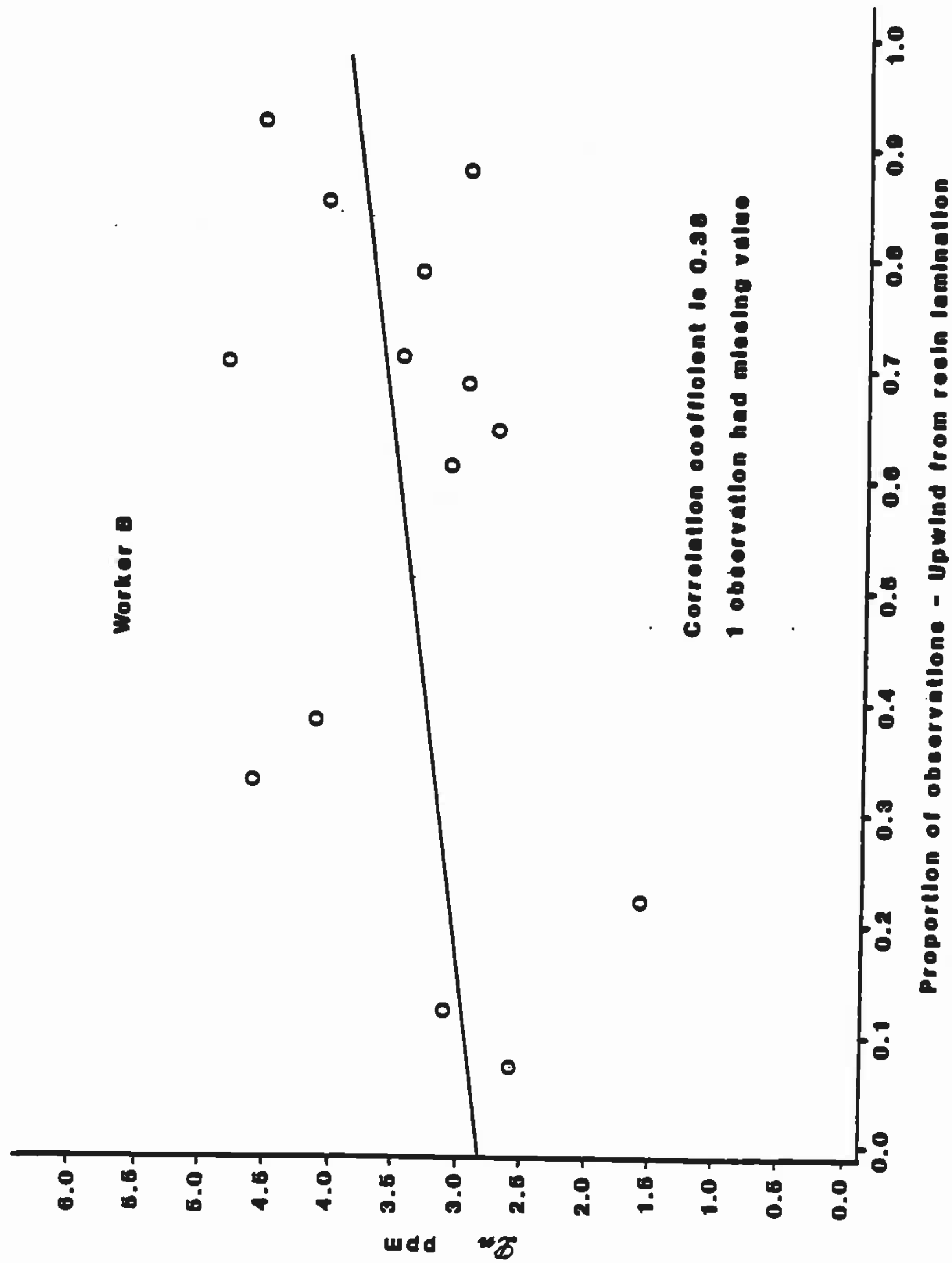
Worker A
Correlation coefficient is 0.839
2 observations had missing volumes
Proportion of observations - Downwind from resin lamination
ppm
4.2
3.9
3.6
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
.30
.40
.50
.60
.70
.80
.90
1.00



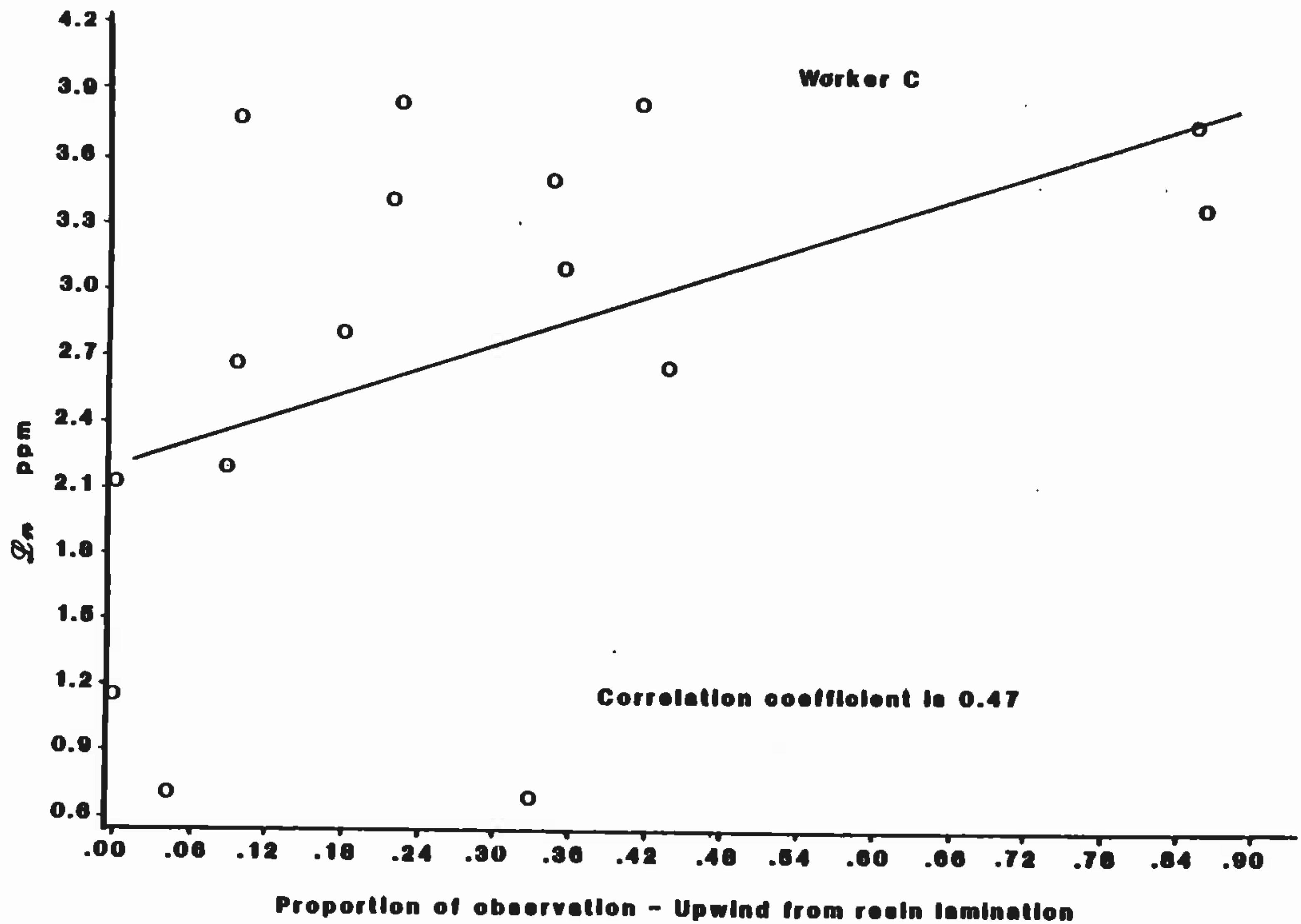
Worker B
ppm
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
.00
.06
.12
.18
.24
.30
.36
.42
.48
.54
.60
.66
.72
.78
.84
.90
Correlation coefficient is -0.15
1 observation had missing value
Proportion of observations - Downwind from resin lamination


Worker C
Correlation coefficient is -0.462
Proportion of observation - Downwind from resin lamination
0.06
0.18
0.30
0.42
0.54
0.66
0.78
0.90
4.2
3.9
3.6
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6


Worker A
4.2
3.9
3.6
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
ppm
.00
.10
.20
.30
.40
.50
.60
.70
Correlation Coefficient is -0.79
2 observations had missing values
Proportions of Observations - Upwind from resin laminations



Worker B
Correlation coefficient is 0.38
1 observation had missing value
Proportion of observations - Upwind from resin lamination
ppm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


Worker C
Correlation coefficient is 0.47
4.2
3.9
3.6
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
Ln ppm
.00
.06
.12
.18
.24
.30
.36
.42
.48
.54
.60
.66
.72
.78
.84
.90
Proportion of observation - Upwind from resin lamination