IN-DEPTH STUDY: A RE-EVALUATION OF STYRENE AND NOISE EXPOSURES IN THE FIBERGLASS-REINFORCED PLASTIC BOAT MANUFACTURING INDUSTRY

at

Island Packet Yachts (IPY)
Largo, Florida

REPORT WRITTEN BY:
Duane R. Hammond, P.E.
Rebecca V. Carlo
Alberto Garcia, M.S.
Leo M. Blade, M.S.E.E., C.I.H.
H. Amy Feng, M.S.

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Applied Research and Technology
Engineering and Physical Hazards Branch
4676 Columbia Parkway, Mail Stop R-5
Cincinnati, Ohio 45226-1998

SITE SURVEYED:	Island Packet Yachts Largo, Florida
SIC CODE:	3732 (Boat Manufacturing and Repair)
NAICS CODE:	336612 (Boat Building)
SURVEY DATE:	February 26- March 1, 2007
SURVEY CONDUCTED BY:	Rebecca V. Carlo Duane Hammond Alberto Garcia Leo M. Blade NIOSH Cincinnati, OH
EMPLOYER REPRESENTATIVES CONTACTED:	Jerry Swartz Engineering Manager, Island Packet Yachts

DISCLAIMER

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The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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ABSTRACT

On February 26 through March 1, 2007, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an in-depth survey to evaluate occupational exposures to styrene vapors at Island Packet Yacht (IPY) in Largo, Florida. This evaluation was conducted as a follow up to the August 2006 evaluation at IPY which suggested that the open overhead doors may have contributed to low styrene concentrations. A second evaluation was conducted to quantify the exposures occurring during open and closed mold processes during the winter when large overhead doors were more likely to be closed and to determine if results are different from the previous assessment. The effectiveness of the styrene controls examined in both studies was evaluated by measuring styrene concentrations in personal breathing-zone and general-area air samples during typical work shifts. The personal breathing-zone samples for the workers in the closed-mold area resulted in a geometric mean styrene concentration of 7.04 to 7.34 parts per million (ppm) during the first evaluation and 6.81 ppm during the second evaluation. During the first evaluation, the geometric mean of the personal-breathing zone styrene samples of workers in the open-molding process was 11.6 ppm for the small parts laminators and approximately 13 ppm for the hull laminator, large part laminator, and the gelcoater. During the second evaluation, the geometric means of the personal breathing-zone samples of workers in the open-molding process were approximately 10 ppm for the gelcoater and between 15 ppm and 18 ppm for the laminators. The general-area air sample results were higher for the second study. All general-area air sample results were below 10 ppm during the first study and between 11 ppm and 15 ppm during the second study. Although several of the measurements collected during the second evaluation were higher than those of the first evaluation, all measurements were below the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 100 ppm and the NIOSH Recommended Exposure Limit of 50 ppm for worker exposure to styrene vapor. Results from both studies indicate that the evaluated controls were effective in controlling styrene vapor under the evaluated conditions.

INTRODUCTION

On February 26 through March 1, 2007, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an in-depth survey to evaluate occupational exposures to styrene vapors at Island Packet Yacht (IPY) in Largo, Florida. This evaluation was conducted as a follow up to the August 2006 evaluation at IPY[1] which suggested that the open overhead doors may have contributed to low styrene concentrations. The purpose of conducting a second evaluation was to quantify the exposures occurring during open and closed mold processes during the winter when large overhead doors were more likely to be closed and to determine if results are different from the previous assessment. The objective of this in-depth survey was to evaluate the styrene vapor exposures occurring at IPY. The specific aims of this field survey were to:

1) Assess the occupational exposures of styrene vapor in air during a vacuum infusion closed-molding process and the traditional open-mold process
2) Evaluate the currently installed ventilation system and make recommendations where needed

The outcome of this study was evaluated in terms of personal breathing-zone styrene exposures of workers who operate the equipment and laborers who work alongside the operators. In addition, styrene concentration measurements were taken at various fixed locations throughout the facility (area samples). For this report, effective engineering controls are those that maintain styrene exposures below the occupational exposure limits—the NIOSH recommended exposure limit (REL), or the OSHA permissible exposure limit (PEL).

This report will focus on the documentation of styrene exposures measured during the closed- and open-molding manufacturing process. In addition, engineering controls and work practice recommendations will be offered where styrene exposures exceed the NIOSH or OSHA exposure criteria.

Background

According to the 2004 Statistics of U.S. Businesses, 51,409 workers were employed in the boat manufacturing industry (most of which were involved in fiber-reinforced plastic boat manufacturing), with 26,633 in firms of 500 employees or less.[2] In the early 1980s, NIOSH conducted a control technology assessment of the boat manufacturing industry, primarily focusing on large FRP boats using open molding techniques. Since then, many changes have occurred in this industry, including the development of closed molding processes and the promulgation of the Environmental Protection Agency's (EPA) Maximum Achievable Control Technology (MACT) standard for boat manufacturing in August of 2001. During meetings with industry trade associations, individual companies expressed an interest in a study to assess and quantify the effectiveness of closed-mold operations and the MACT technologies for reducing occupational styrene exposures. In addition, trade-association representatives have also expressed interest in NIOSH developing cost-effective ventilation controls for open-molding processes, recognizing that open-molding processes emit the most styrene vapors and are the processes most widely used in manufacturing facilities today.

Exposure Hazards of Styrene

Humans exposed to styrene for short periods of time through inhalation may exhibit irritation of the eyes and mucous membranes, and gastrointestinal effects.[3] Styrene inhalation over longer periods of time may cause central nervous system effects including headache, fatigue, weakness, and depression. Exposure may also damage peripheral nerves and cause changes to the kidneys and blood. Numerous studies have shown that styrene exposures were linked to central and peripheral neurologic,[4,5,6] optic,[7,8] and irritant[9] effects when occupational exposures to styrene vapors in air were measured at concentrations greater than 50 parts per million (ppm). There is also evidence concerning the influence of occupational styrene exposure on sensory nerve conduction indicating that: (1) 5% to 10% reductions can occur after exposure at 100 ppm or more; (2) reduced peripheral nerve conduction velocity and sensory amplitude can occur after styrene exposure at 50 to 100 ppm; (3) slowed reaction time appears to begin after exposures as low as 50 ppm; and, (4) statistically significant loss of color discrimination (dyschromatopsia) may occur.[10] Some other health effects of low-level styrene exposure include ototoxicity in workers and experimental animals. Styrene exposure can cause permanent and progressive damage to the auditory system in rats even after exposure has ceased.[11,12] Styrene has been shown to be a potent ototoxicant by itself, and can have a synergistic effect when presented together with noise or ethanol.[13,14,15,16]

Evaluation Standards

The primary sources of environmental evaluation standards and guidelines for the workplace are: (1) the OSHA Permissible Exposure Limits (PELs);[17] (2) The NIOSH Recommended Exposure Limits (RELs);[18] and (3) the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®)[19]. Employers are mandated by law to follow the OSHA limits; however, employers are encouraged to follow the most protective criteria.

Styrene

The NIOSH REL for styrene vapor in air is 50 ppm for a 10-hour time-weighted average (TWA) (meaning the limit applies to the average exposure during a work day of up to 10 hours and a work week of up to 40 hours), with a 15-minute short-term exposure limit (STEL) of 100 ppm, limiting average exposures over any 15-minute period during the work day.[20] These recommendations are based upon reported central nervous system effects and eye and respiratory irritation. The OSHA PEL for styrene is 100 ppm for an 8-hour TWA exposure, with a ceiling limit of 200 ppm. The ceiling limit restricts exposures for any portion of the work day. The American Conference of Governmental Industrial Hygienists (ACGIH) revised its Threshold Limit Value (TLV®) in 1997, and recommends styrene be controlled to 20 ppm for an 8-hour TWA exposure with a 40 ppm, 15-minute STEL. The Swedish Work Environment Authority has an occupational exposure level limit value (LLV) for styrene of 20 ppm and a short term value (STV) of 50 ppm.[21] The German Federal Institute for Occupational Safety and Health has an occupational exposure limit value of 20 ppm for styrene.[22]

In February 1996, the Styrene Information and Research Center (SIRC) and three other styrene industry trade associations (American Composites Manufacturers Association, National Marine Manufacturers Association, and the International Cast Polymer Association) entered into a precedent-setting arrangement with OSHA to voluntarily adhere to the 50-ppm level set by the 1989 update of the OSHA PEL (which was later vacated by the courts). The SIRC encouraged its members to continue to comply with the 50-ppm standard as an appropriate exposure level for styrene, regardless of its regulatory status.[23]

Maximum Achievable Control Technology

The EPA has identified the FRP boat manufacturing industry as a major source of Hazardous Air Pollutants (HAPs)—mainly styrene. The final MACT regulation was issued to reduce HAPs for new and existing boat manufacturing facilities. The MACT standard affects any boat manufacturing stationary facility that emits or can potentially emit 10 tons per year of a single HAP or 25 tons per year of combined HAP. The MACT covers: (1) open molding resin and gel coat operations; (2) resin and gel coat mixing operations; (3) resin and gel coat application equipment cleaning operations; (4) carpet and fabric adhesive operations. The MACT standard requires boat manufacturers using open molding to adopt stringent air pollution control technologies in order to reduce environmental releases of styrene vapor in the air. Closed molding is one method for demonstrating compliance with the Boat Manufacturing MACT. Under the rule, boat manufacturers wishing to continue using open-molding operations must use one of the following options: (1) purchase materials that meet the organic HAP content requirement; (2) meet the HAP content requirements for resin and gel coat operations on a weighted average basis; (3) use emissions averaging among different resin and gel coat operations: or, (4) use an add-on control device.[24] Closed molding is exempt from the MACT standard.

<u>Styrene Usage</u>

The major chemical component of concern in terms of occupational exposures in the FRP process is styrene. Styrene is a fugitive emission, which evaporates from resins, gel coats, solvents, and surface coatings used in the manufacturing process. The thermo-set polyester production and tooling resins, along with the gelcoats, used at this plant are compliant with the U.S. EPA requirements for MACT. All of the various products used at IPY which contain styrene are listed in Table 1 along with their application method and percent styrene by weight. The concentrations of styrene in tooling and production resins vary depending on the color of the gelcoat and other manufacturing environmental factors (temperature, humidity, etc.).

Table 1: List of all products used at IPY containing styrene

Name	Application	% Styrene
General Purpose Resin	Roller	35
General Purpose Resin	Hand Lay-up	35
ASCC Vinyl Ester	Roller	34.1
Tooling	Roller	34.1
Casting Resin	Hand Lay-up	35
Gelcoat-Lite Camel	Spray	27
Gelcoat-Lite Ivory	Spray	28
PG-9 Putty	Hand	16
SprayCore (Polycore)	Spray	29
Deck Bonding Putty	Hand	26
Styrene	Spray	100
Duratec-All varieties	Spray	21
Liner Putty	Hand	14
Tooling Gel	Spray	37
Dion Vinyl Ester Resin	Hand	45
Hexion Infusion	Infusion	42.5
Dion Vinyl Ester Resin	Infusion	45

General Facility Information

Island Packet Yachts is a small sailing yacht manufacturing company employing approximately 150 to 175 employees. The facility is on nine acres of land and split on two sides of a street (east and west). The west site contains buildings with 42,000 square feet of space and the east site has a single 64,000 square feet building. The sailing yachts IPY manufactures range in size from 37 to 50 feet. Yacht production is approximately 1 yacht per week during a five-day week with one shift daily from 5:00 AM to 1:30 PM. Most of the products made at IPY are sail boats. The six models are: Big Fish, SP Cruiser, IP 370, IP 440, IP 445, and IP485. In addition, two power boat models are manufactured—the Packet Craft Express and the PY Cruiser. The vast majority of FRP production manufacturing is done in an area known as the glass shop. The glass shop is located on the northeast section of the building on the west site. For building layout, see

Figure 1.

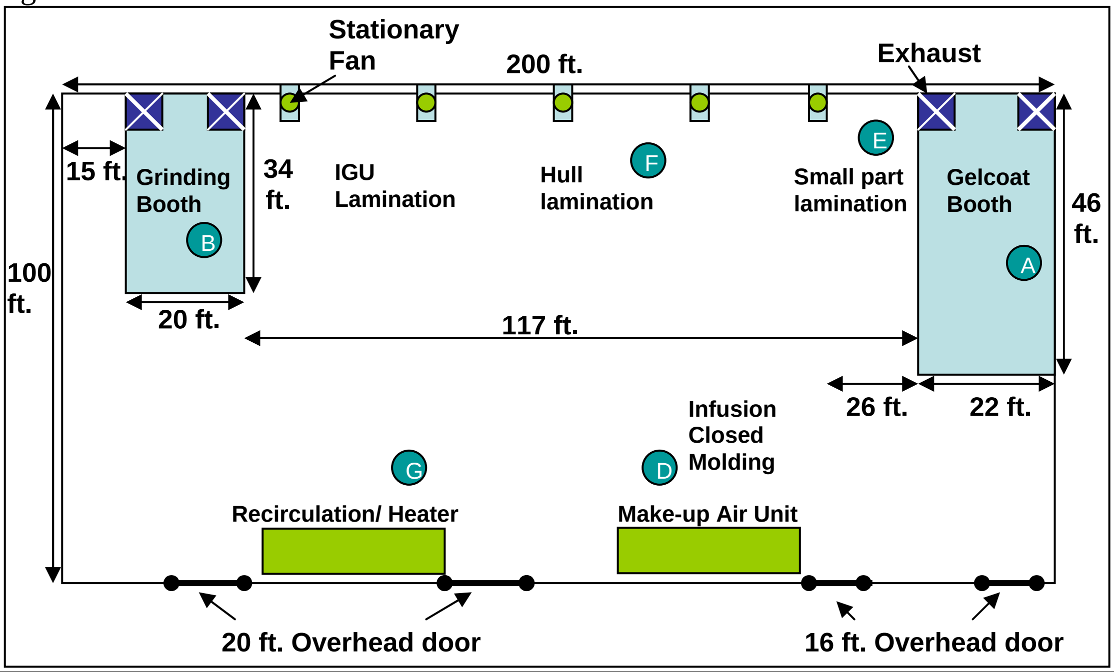

Figure 1: Overhead view of Glass Shop and Ventilation System Components (letters indicate location of area samples)

<u>Process Description</u>

The main process used to manufacture sailing yachts at IPY is open molding. The open-molding operation is a labor intensive process which requires several employees working on a single part at the same time. The work load distribution for this facility is as follows: two to three employees work in hull lamination, three to five employees work in deck lamination, one to two employees work in small part lamination, and three to five employees for the internal glass unit (IGU) construction and lamination. Two to three employees also worked in the gel coat spray booth and grinding booth. The labor distribution varies depending on demand and boat production schedules. All activities which involve the use of styrene-based products were sampled during this study.
While closed molding at IPY is not yet widely used, IPY is exploring and expanding their use of closed-molding technologies. IPY representatives have expressed their concern regarding the cost effectiveness to manufacture in a closed-mold. IPY uses a closed-molding Vacuum Infusion Process (VIP) to make small parts such as: hatch covers and water tanks; however, the gelcoating operation required for small parts is still an open-molding process. The work load depends on production requirements; two to three employees work in the closed-molding infusion area which is not separated from the glass shop.

The following is a brief description discussing how FRP boats are made using both the open-molding and closed-molding processes specific to IPY's facility.

Gelcoating

Before applying the gelcoat, the mold is cleaned. When needed, a wax is applied to the mold surface to ensure an easy part-mold separation. Once the mold is cleaned and waxed, it is placed in a ventilated spray booth. Gelcoat is applied to the mold to provide the smooth outer finish of the hull, deck, or small-part. When spraying large hulls, the gel coaters spray one half of the mold, and then rotate the mold longitudinally on its stand to complete the other half. Small parts are gelcoated in the same spray booth. The small parts molds are fastened to carts and moved through the plant manually. Gelcoat is sprayed by two gelcoaters (specified in this report as gelcoater, and gelcoater assistant) using atomized spray guns (Magnum Venus, Pro Gun No. 58603-3 with Air Assist VPA-100; Kent, Washington) inside a spray booth located on the northeastern side of the glass shop. See Figure 2. The gelcoating assistant also spends part of his time inside the gelcoat spray booth prepping the molds (taping edges, preparing spray gun, etc.) prior to gelcoating and moving parts left in spray-booth to their designated areas. After the parts are sprayed, they remain in the booth for approximately 30 minutes allowing the gelcoat to cure. The spray booth is not completely enclosed. The south end of the spray booth does not contain a door and was kept open during spraying. Make-up air enters the booth from the south end and is exhausted from the north end through exhaust vents (16 ft. x 44 ft. x 20 in.) located on the east and west corners of the spray booth wall. The filters in the exhaust vents are paper honeycomb with tight fiber strands. The existing spray booth exhaust fan is designed to pull 35,000 cubic feet per minute (CFM) of air. The gelcoating supervisor is seldom inside the spray booth while the gelcoating is taking place. His supervising tasks include inspection of part before and after gelcoating, documentation of material used, and organization of parts coming in and out of the gelcoat booth.

Figure 2: Gelcoat booth containing small part molds during the curing process

Hull and Deck Lamination

After gelcoating, the hulls, decks, and small part molds are transported to their respective areas. See Figure 1. Decks and hulls are laminated in a similar way. With the exception that skin coat applications on hulls are laminated with vinyl ester resin. A barrier-skin coat (glass fiber fabric and polyester resin) is applied after the gelcoat (as part of lamination) to make hulls and decks less permeable to moisture and to reduce negative cosmetic damages to the layer of gelcoat due to the exothermic reaction taking place while resin is curing. Resin is not sprayed during any part of the lamination process. During hull lamination, resin is released through low-flow pressure-fed perforated rollers attached to a long-handled applicator. A valve is used to control the flow through the roller. A pump mixes and activates the resin once the catalyst is introduced. The pump is attached to the long-handled applicator. This mobile device allows for the worker to be in close proximity to the hull surface while minimizing the release of styrene vapor. See Figure 3. For the purposes of this report, all workers involved in hull lamination are classified as hull laminators.

Figure 3: Large part laminator releasing resin using the pressure-fed perforated rollers

Additional layers of fiberglass cloth saturated with resin are added in layers until the part attains its final desired thickness. These layers are compressed by rolling the top surface by hand. During deck lamination, a six inch metal rolling head attached to a wooden handle is used to eliminate any air pockets between the layers of resin-saturated fiberglass. Nearly twice as much resin is used to laminate hulls as is used on decks. A table displaying the resin usage for each section of the boat can be found in Table 2. A unique aspect of sailing yachts is the keel cavity that is deeper in sailboats than most other FRP boats. The keel is manufactured as part of the hull. This keel is problematic during lamination; potentially causing high exposures.

Lamination and Assembly of Internal Glass Unit (IGU)

The Internal Glass Unit (IGU) is the core structure of the boat. The assembly process begins with the hull, followed by the IGU, and floor timber. The IGU which is built upside down has floor timbers bonded to it on the mold. See Figure 4. Once the structure is demolded it is turned right side up and is complete. Subsequently, the structure is bonded into the hull. Each section is bonded using fiberglass fabric pieces laid out on a piece of cardboard and soaked with resin using a small brush. These pieces are then raised from the cardboard, passed to another worker, placed on the working area (laminating surface), and rolled by hand to eliminate any air pockets. Pieces of wood are inserted throughout the internal glass unit for ease of attachment of interior furniture or flooring at a later time. There are approximately six employees working on this part at one time. Since the resin application process is similar for the deck laminators and IGU laminators, the air-samples taken for these two jobs were grouped together and classified as large part laminator.

Figure 4: Internal Glass Unit (IGU)

Small Parts Laminating Process

Parts such as engine or hatch covers—pieces not part of the deck or hull mold—were considered small parts. Small parts molding was located in the northwest corner of the plant between the hull lamination and the gelcoat booth. These parts were constructed in a similar fashion to the decks. Molds came out of gelcoating and were moved manually on wheeled supports to the small parts area. Layers of fiberglass mats and resin were added to the mold then rolled and compressed by hand. Compared to the hull and deck molding processes, small parts production used much less glass and resin. Workers involved in the fabrication of small parts were classified as small parts laminator.

Table 2: Example of quantity of resin used for a 48 ft. yacht

Boat Model 485 (Boat No. 51)	
	lbs. of resin
Hull	
Skin	324.7
Lamination 2	707
Lamination 3	450.8
Lamination 4	434.7
Lamination 5	559.4
Sub-total	**2476.6**
IGU	
Skin	238.3
Lamination 2	453.1
Lamination 3	286.1
Bond Wood	167.4
Sub-total	**1144.9**
Deck	
Skin	300.8
Lamination 2	632.5
Deck Bubble 1 & 2	497.8
Lamination 3	460.4
Sub-total	**1891.5**
Headliner	
Skin & Lam. 2	303.2
Lamination 3	425
Sub-total	**728.2**
Grand-total	**6241.2**

Closed Molding

The Vacuum Infusion Process (VIP) is a closed-molding pressure driven method that uses a vacuum to pull resin into fiberglass reinforcement plies inside the mold cavity. A single-sided mold is used with a film cover to form an air-tight seal under lower than atmospheric pressure. The inside of the mold has to be coated with a gel-coat finish similar to open-molding. The resin is pulled through the reinforcement fibers using a pressure gradient produced by an external vacuum pump. The vacuum pump is connected to the mold cavity by a series of rigid plastic tubes. Once the resin has cured, the composite part is de-molded, trimmed, and post cured. Advantages of VIP include higher fiber-content parts with fewer voids, and more dimensionally consistent products compared to open molding. Compared to open molding, this closed-molding technology may substantially reduce environmental emissions and worker exposure to styrene.

Safety

Ventilation

The glass shop houses the primary exhaust route in the entire building. Two sets of fans and stacks exhaust 35,000 cfm of air each and were located in the northeast and northwest booths. A Dwyer manometer was installed adjacent to each cell to monitor the pressure differentials across the filters installed at the face of the hood. When the manometer read 0.20 inches of water, the filters were changed in order to maintain the designed air flow at each hood. A heater with a fan was used for make-up air. Systems installed in this building were adjusted for weather conditions, mainly heat and humidity. The exhaust fans and booths were installed by Collins Myers located in the St. Petersburg/ Clearwater, Florida area, but the heaters and makeup air fans were installed by C&C Enterprises in Kissimmee, FL. A series of two to four industrial duty air circulator fans (Dayton, model no. 3C218G) were used throughout the glass shop to move air and aid in cooling of personnel during the hot summer months. These fans were positioned approximately 20 feet from the edge of nearly all operations. The fan specifications were: ¼ hp, 1725 revolutions per minute (RPM), 24-inch diameter, and two to three are in parallel.

Personal Protective Equipment

Safety glasses with side shields were required to be worn at all times in the facility's manufacturing areas as company policy. All laminators, gun-operators, gelcoaters, and grinders wore Tyvek® suiting. Impermeable gloves were available for workers to use and are required when laminating. Respiratory protection was not required for any of the workers; however, respirators were available for workers who desired respiratory protection. It was observed that several of the laminators wore particulate masks (models: MOLDEX 2400, NORTH 7130, and 3M 8000). All grinders wore ear plugs and ear muffs (Competitor, Radians) which attenuate noise at 26 dB when worn over the head.

METHODS

Air Sampling for Styrene

Personal breathing-zone and general-area air samples for styrene were collected and analyzed following NIOSH Method 1501(Hydrocarbons, Aromatic) (NMAM, NIOSH Manual of Analytical Methods). Samples were collected on SKC sorbent tubes (Model number 226-01, Anasorb CSC, Coconut Charcoal, Lot #2000). The tubes were 7 centimeters (cm) long with a 6 millimeter (mm) outer diameter and a 4-mm inner diameter. The ends were flame-sealed, and contained two sections of activated coconut shell charcoal, 100 milligrams (mg) in front and 50 mg in back, separated by a 2-mm urethane foam plug. A glass wool plug precedes the front section, and a 3-mm urethane foam plug follows the back section. After breaking the sealed ends, each tube was connected to a Gilian low flow pump or an SKC Pocket Pump set at a flow rate of 0.3 liters per minute (L/min). For personal breathing-zone samples, the air inlet of the sampling apparatus was secured in each worker's breathing zone with a lapel clip, and the battery-powered pump clipped to the worker's belt. A calibration was performed on each pump before and after sampling. In addition, two field blank samples were taken each day to ensure that the sample media was not contaminated and to account for variance in sample preparation.

The analyses of the charcoal tube samples for styrene were performed by Clayton Group Services in Novi, MI. The samples were analyzed by removing the individual sections of the charcoal tube and placing them into separate vials. The glass wool and the foam plugs that divide the sections of charcoal were discarded. The individual sections were then chemically desorbed by using 1 mL of carbon disulfide. The samples were placed on a mechanical shaker for a minimum of 30 minutes before analyzed by gas chromatography with flame ionization detection (GC/FID) in accordance with NIOSH Method 1501. The limit of detection and limit of quantification for styrene for this sample set was 0.33 and 2.93 ppm respectively.

General-area samples were collected to better understand the effectiveness of the installed engineering controls using the same type of sampling apparatus as used for the personal sampling, but placed in stationary locations. These samples were located to determine how well the ventilation system was performing throughout the plant, and to assess the spread of the styrene vapor throughout the facility. Area samples were placed in eastern and western gelcoat spray booths, tooling area, closed-mold area, the small part lamination, and large part lamination area. See Figure 1 for area sample locations.

Once the sample results were received from the analytical laboratory, the styrene breathing zone concentrations and general-area concentrations were calculated using Equation 1. The concentration from milligrams per meter cubed was converted to parts per million.

$$C = \frac{m}{V \times 4.26} \qquad (1)$$

Where,
C = styrene concentration, ppm
m = mass of styrene per sample, μg
V = volume of air sample, L
Note: 4.26 is the constant used for styrene to convert from mg/m^3 to ppm obtained from: NMAM (NIOSH Manual of Analytical Methods) 1501(Hydrocarbons, Aromatic)

Statistical Analysis and Results

The sample distributions were checked for normality using the Shapiro-Wilk test. The results of this test suggested the data were log-normally distributed; subsequently, all data were log-transformed for statistical analysis. Personal samples and area samples were analyzed separately. Arithmetic mean, geometric means, standard deviation, and 95% confidence limits are included in Table 3.

Table 3: Personal and area sample statistical results for styrene vapor for both studies

		Study 1						Study 2				
Sample Type	**Job title or area**	**Geometric Mean [ppm]**	**Geometric standard deviation**	**Lower 95% Confidence Limit [ppm]**	**Upper 95% Confidence Limit [ppm]**	**n**		**Geometric Mean [ppm]**	**Geometric standard deviation**	**Lower 95% Confidence Limit [ppm]**	**Upper 95% Confidence Limit [ppm]**	**n**
area	Gelcoat Booth	7.92	1.39	4.66	13.45	4		15.1	1.26	10.42	21.73	4
area	Grinding Booth	6.63	1.12	5.51	7.98	4		9.82	1.34	6.18	15.6	4
area	Tooling Area	1.91	1.35	1.19	3.07	4						
area	Infusion Closed Molding	5.67	1.2	4.22	7.6	4		7.87	1.32	5.05	12.25	4
area	Small Parts Lamination	6.46	1.27	4.39	9.51	4		9.49	1.34	5.96	15.13	4
area	Hull Lamination	6.57	1.23	4.75	9.1	4		11.3	1.17	8.79	14.53	4
area	Recirculation/Heater	7.06	1.23	5.07	9.84	4		8.52	1.5	4.45	16.3	4
personal	Gelcoater	13.7	1.22	9.97	18.68	4		10	1.97	4.92	20.35	6
personal	Gelcoat Assistant	4.27	1.68	1.87	9.76	4						
personal	Gelcoat Supervisor	10.2	1.18	7.81	13.17	4						
personal	Grinding/Cutting	5.15	1.24	4.31	6.15	8		9.18	1.39	7.43	11.34	12
personal	Hull Laminator	13	1.28	11.03	15.35	11		16.5	1.18	15.04	17.99	16
personal	Closed Molding (VIP)	7.34	1.39	4.33	12.45	4		6.81	1.74	4.08	11.35	7
personal	Infusion Small Parts	7.04	1.26	4.87	10.16	4						
personal	Large Part Laminator	13.5	1.43	11.75	15.52	28		15.5	1.52	13.14	18.26	27
personal	Putty and Cutting	6.66	1.12	5.07	8.77	3						
personal	Small Part Laminator	11.6	1.28	9.39	14.2	8		17.6	1.33	14.64	21.13	12
personal	Tooling	2.58	1.96	1.68	3.96	12						
personal	Small Tanks							4.87	1.39	2.89	8.21	4

Area Samples

Area samples were categorized into seven subgroups. A one-factor (location) analysis of variance model with Turkey's multiple comparison procedures was used to test the differences among area concentrations. A statistically significant difference was found among area sampled (p=0.0001). Turkey's multiple comparison procedures indicated that the concentrations in the tooling area were statistically significantly lower than the concentrations of any other evaluated area at the 5% significance level. No statistically significant differences were found among areas samples between the gelcoat booth, grinding booth, infusion closed molding area, small parts lamination, hull lamination and recirculation/heater area.

Personal Samples

There were seven job categories for personal samples. For each individual worker, means of all four days of exposure were used for the analysis. A one-factor (job category) analysis of variance model with Tukey’s multiple comparison procedure was used to test the differences among job categories. A statistically significant difference was found among job category (p=0.0005). The small parts laminator and large parts laminator had significantly higher exposures than exposures of the griding/cutting, gelcoater, closed molding (VIP), and small tanks. The hull laminator had significantly higher exposures than that of the gelcoater, closed molding (VIP), and small tanks. No significant differences were found among the small parts laminator, hull laminator and large part laminator, between the hull laminator and griding/cutting or among griding/cutting, gelcoater, closed molding (VIP), and small tanks.

Comparison of Study and Job Category

For personal data, a two factor (study and job category) analysis of variance procedure was used to analyze the data. For the comparison between studies, “study 1” refers to the August 2006 NIOSH study at IPY, and “study 2” refers to the February 2007 NIOSH study at IPY. Statistically significant differences were found between study (p=0.017) and among job category ($p<0.001$). Study 2 had higher mean exposures than the exposures of study 1. The hull laminator, large parts laminator, and small parts laminators had higher exposures than the exposures of the small tanks, closed molding (VIP), grinding/cutting, and gel coater. No differences were found between job categories of small tanks, closed molding (VIP), grinding/cutting, gel coater and between the hull laminator, large parts laminator, and small parts laminator. This result is only consistent with the results from the analysis of the second study.

For area samples, a two factor (study and job area) analysis of variance procedure was used to analyze the data. Statistically significant differences were found between study ($p<0.0001$) and among job area (p=0.003). No significant interaction between study and job area was found which made the interpretation of the result easier. Study 2 had higher mean exposures than the exposures of study 1; area samples in the gel coat booth were higher than samples in the grinding booth, small parts lamination, closed molding (VIP), or recirculation/heater area. No differences were found between area samples in the gel coat booth and hull lamination, and between area samples in hull lamination, the grinding booth, small parts lamination, closed molding (VIP), and the recirculation/heater area.

The calculated geometric means (measure of central tendency), standard deviations, lower and upper 95% confidence limits, and sample size are shown for comparison of personal and area samples by study in Table 3. The individual results sorted by job title or area location for the first and second study are presented in Appendix 1 and Appendix 2 respectively. The tables in Appendix 1 and Appendix 2 list each sample taken (either personal breathing-zone or general-area), job title (if personal breathing-zone sample) or specific location (if general-area sample), date, sample ID, and concentration (µg/sample and ppm).

DISCUSSION

The results from the personal and area air styrene measurements from this study and the previous evaluation at IPY indicate that styrene concentrations were reasonably well controlled. The higher personal and area air styrene concentrations measured during the second study were likely a result of closing the overhead doors. However, the personal and area air styrene concentrations for both studies were well below the OSHA PEL of 100 ppm and the NIOSH REL of 50 ppm. Additionally, the results were lower than concentrations measured by NIOSH researchers during evaluations of occupational styrene exposures in facilities that manufacture recreational power boats using open-molding.[25,26] The low air styrene concentrations measured at IPY were likely due to the lamination process of releasing resin through low-flow pressure-fed perforated rollers instead of spraying resin with chopped glass.

One of the goals of the study was to evaluate occupational exposures near the vacuum infusion closed-molding process and to compare the results with results from exposures occurring near open-molding processes. However, it was difficult to quantify a true comparison between the two processes since closed-molding and open-molding share the same room and ventilated space. During the second evaluation, the geometric mean concentration of the personal sample of the closed-molding VIP workers were lower than the geometric mean concentration of any of the area samples collected at any location in the plant. Therefore, the personal sample of the closed-molding worker was more representative of an area sample of the well mixed plant air and not representative of the closed-molding process. The personal samples of the closed-molding VIP workers were lower than area samples because the workers spent time outside of the plant on breaks. It is expected that exposures resulting from the vacuum infusion closed-molding process would be significantly lower than open molding processes since the parts are smaller and the process takes place in a sealed environment, but it was not possible to quantify exposures from the closed-molding VIP process independently from other process taking place in the plant.

The data indicate that the styrene vapor concentrations measured throughout the plant were consistent during both evaluations. The consistent concentrations throughout the plant were likely a result of mixing that took place as a result of the many stationary fans spread throughout the facility and because the ventilation system installed in the glass shop was designed as a general-ventilation system. Based on the geometric mean styrene concentration measured during both evaluations, it appears that the air inside the glass shop was well mixed.

CONCLUSIONS AND RECOMMENDATIONS

At the time of this evaluation, all of the measured personal breathing-zone and area air styrene concentrations were well below the OSHA PEL of 100 ppm and NIOSH REL of 50 ppm. Additionally, nearly all of the geometric mean personal breathing-zone and area air styrene concentrations were lower than recommended exposure limits for styrene vapor. Efforts should be made to continue to keep styrene concentrations below applicable exposure criteria. The following recommendations are provided to further protect workers and to maintain a safe and healthy working environment.

• It is recommended that the closed-molding VIP be performed in a separate space from the open-molding operations. Physically separate open and closed-molding areas would help prevent the workers in the closed-molding area from being unnecessarily exposed to styrene vapors from the open molding processes. It is also recommended that manufacturers continue to explore the use of closed-molding processes where possible.

• During the current evaluation, it was observed that several workers were not wearing respirators properly. Several of the workers had excessive facial hair which is known to dramatically reduce the ability of a respirator to form a proper seal on the face of a worker. In the previous evaluation, it was observed that several employees wore particulate respirators that consisted of a Moldex 2400, North 7130, or 3M 8000. The Moldex 2400 protects against both particulates and organic vapors. The other two types of respirators are N-95 particulate respirators and do not protect against organic vapors. If a respirator is provided for an employee it should have the ability to remove organic vapors (i.e., styrene vapors). If particulates are of concern, the respirator should be able to remove both the particulate and the organic vapors. In accordance with 29 CFR 1910.134, if the employer determines that any voluntary respirator use is permissible, the employer shall provide the respirator users with the information contained in Appendix D of 29 CFR 1910.134.[27]

• Workers did not consistently wear gloves and PPE when performing tasks that required routine contact with the resin. Since styrene is listed with a skin notation in the ACGIH TLV, and skin contact with styrene and other chemicals in the resin can cause dermatitis, proper gloves that protect workers against contact with styrene should be worn by all employees who have the potential to come into contact with the resin.

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APPENDIX 1

Job Title	Date	Sample ID	Result (ug/Sample)	Concentration [ppm]
Infusion	8/15/2006	**101**	**490**	**6.32**
Infusion Small Parts Supervisor	8/15/2006	**102**	**380**	**6.06**
Area D	8/15/2006	**103**	**330**	**4.46**
Small Parts Laminator	8/15/2006	**104**	**480**	**10.63**
Blank	8/15/2006	**105**	**0**	**0.00**
Blank	8/15/2006	**106**	**0**	**0.00**
Small Parts Laminator	8/15/2006	**107**	**730**	**9.09**
Infusion Small Parts Supervisor	8/16/2006	**109**	**320**	**8.52**
Hull Laminator	8/16/2006	**110**	**730**	**11.84**
Hull Laminator	8/15/2006	**111**	**830**	**11.11**
Small Tanks	8/15/2006	**112**	**370**	**5.07**
Hull Laminator	8/15/2006	**113**	**650**	**10.89**
Large Part Laminator	8/15/2006	**114**	**1200**	**15.94**
Area F	8/15/2006	**115**	**370**	**4.97**
Hull Laminator	8/15/2006	**116**	**810**	**11.11**
Blank	8/15/2006	**118**	**0**	**0.00**
Putty and Cutting	8/15/2006	**119**	**410**	**7.11**
Blank	8/15/2006	**120**	**0**	**0.00**
Area A	8/15/2006	**121**	**390**	**4.89**
Gelcoat Supervisor	8/15/2006	**122**	**580**	**10.50**
Tooling	8/15/2006	**123**	**86**	**1.35**
Area E	8/15/2006	**124**	**360**	**4.54**
Gelcoat	8/15/2006	**125**	**920**	**12.88**
Tooling	8/15/2006	**126**	**230**	**4.04**
Tooling	8/15/2006	**127**	**210**	**3.12**
Gelcoat Assistant	8/15/2006	**128**	**290**	**4.85**
Area C	8/15/2006	**130**	**220**	**2.80**
Large Part Laminator	8/15/2006	**131**	**710**	**12.61**
Grinding/Cutting	8/15/2006	**132**	**410**	**6.56**
Large Part Laminator	8/15/2006	**133**	**1100**	**19.83**
Area B	8/15/2006	**135**	**520**	**6.69**
Large Part Laminator	8/15/2006	**136**	**750**	**12.52**
Area G	8/15/2006	**137**	**420**	**5.52**
Large Part Laminator	8/15/2006	**138**	**640**	**8.52**

Large Part Laminator	8/15/2006	**139**	**1000**	**14.10**
Large Part Laminator	8/15/2006	**140**	**1200**	**19.81**
Area C	8/16/2006	**141**	**120**	**1.44**
Gelcoat Assistant	8/16/2006	**142**	**130**	**2.02**
Tooling	8/16/2006	**143**	**56**	**1.00**
Tooling	8/16/2006	**144**	**280**	**3.66**
Tooling	8/16/2006	**145**	**500**	**6.58**
Infusion	8/16/2006	**146**	**890**	**11.62**
Area E	8/16/2006	**147**	**570**	**6.86**
Gelcoat	8/16/2006	**148**	**1200**	**17.55**
Small Parts Laminator	8/16/2006	**149**	**630**	**9.92**
Area A	8/16/2006	**150**	**770**	**9.70**
Area D	8/16/2006	**151**	**460**	**6.84**
Small Parts Laminator	8/16/2006	**152**	**730**	**8.92**
Large Part Laminator	8/16/2006	**153**	**1400**	**22.26**
Large Part Laminator	8/16/2006	**154**	**1500**	**23.48**
Gelcoat Supervisor	8/16/2006	**155**	**500**	**7.97**
Large Part Laminator	8/16/2006	**156**	**1300**	**16.66**
Large Part Laminator	8/16/2006	**157**	**1600**	**20.69**
Area B	8/16/2006	**158**	**540**	**7.23**
Large Part Laminator	8/16/2006	**159**	**1000**	**15.66**
Grinding/Cutting	8/16/2006	**160**	**390**	**5.07**
Large Part Laminator	8/16/2006	**161**	**350**	**5.18**
Area F	8/16/2006	**162**	**510**	**6.44**
Area D	8/17/2006	**163**	**420**	**5.45**
Area G	8/16/2006	**164**	**720**	**9.18**
Hull Laminator	8/16/2006	**165**	**790**	**9.89**
Small Tanks	8/16/2006	**166**	**150**	**2.18**
Gelcoat Supervisor	8/17/2006	**167**	**740**	**11.37**
Putty and Cutting	8/16/2006	**168**	**400**	**5.87**
Large Part Laminator	8/16/2006	**169**	**2000**	**26.12**
Grinding/Cutting	8/16/2006	**170**	**470**	**7.26**
Tooling	8/17/2006	**171**	**240**	**3.52**
Infusion	8/17/2006	**172**	**600**	**7.37**
Area A	8/17/2006	**173**	**770**	**10.04**
Blank	8/16/2006	**174**	**0**	**0.00**
Area E	8/17/2006	**175**	**580**	**7.90**

Small Parts Laminator	8/17/2006	**176**	**1200**	**14.96**
Blank	8/16/2006	**177**	**0**	**0.00**
Blank	8/16/2006	**178**	**0**	**0.00**
Blank	8/16/2006	**179**	**0**	**0.00**
Infusion Small Parts Supervisor	8/17/2006	**180**	**550**	**8.62**
Large Part Laminator	8/17/2006	**181**	**860**	**11.58**
Large Part Laminator	8/17/2006	**182**	**780**	**12.33**
Large Part Laminator	8/17/2006	**183**	**720**	**9.37**
Grinding/Cutting	8/17/2006	**184**	**220**	**4.07**
Large Part Laminator	8/17/2006	**185**	**890**	**11.75**
Grinding/Cutting	8/17/2006	**186**	**250**	**4.11**
Large Part Laminator	8/17/2006	**187**	**790**	**9.90**
Hull Laminator	8/17/2006	**188**	**1300**	**20.00**
Area F	8/17/2006	**189**	**560**	**14.17**
Area B	8/17/2006	**190**	**420**	**5.61**
Hull Laminator	8/17/2006	**191**	**1200**	**16.08**
Tooling	8/17/2006	**192**	**50**	**0.76**
Area G	8/17/2006	**193**	**530**	**7.06**
Gelcoat Assistant	8/17/2006	**194**	**340**	**5.11**
Grinding/Cutting	8/17/2006	**195**	**350**	**4.57**
Small Parts Laminator	8/17/2006	**196**	**1100**	**16.47**
Large Part Laminator	8/17/2006	**197**	**590**	**7.73**
Hull Laminator	8/17/2006	**198**	**1400**	**18.83**
Large Part Laminator	8/17/2006	**199**	**930**	**11.79**
Gelcoat	8/17/2006	**200**	**730**	**10.92**
Area C	8/17/2006	**201**	**120**	**1.59**
Small Parts Laminator	8/18/2006	**202**	**480**	**10.08**
Infusion Small Parts Supervisor	8/18/2006	**203**	**360**	**5.51**
Area D	8/18/2006	**204**	**460**	**6.20**
Small Parts Laminator	8/18/2006	**205**	**930**	**14.87**
Blank	8/17/2006	**206**	**0**	**0.00**
Blank	8/17/2006	**207**	**0**	**0.00**
Blank	8/17/2006	**208**	**0**	**0.00**
Blank	8/17/2006	**209**	**0**	**0.00**
Tooling	8/17/2006	**210**	**180**	**2.30**
Gelcoat	8/18/2006	**211**	**870**	**14.04**

Gelcoat Supervisor	8/18/2006	**212**	**730**	**11.14**
Tooling	8/18/2006	**213**	**320**	**4.26**
Area E	8/18/2006	**214**	**580**	**7.09**
Tooling	8/18/2006	**215**	**110**	**1.70**
Tooling	8/18/2006	**216**	**370**	**4.83**
Gelcoat Assistant	8/18/2006	**217**	**430**	**6.67**
Area C	8/18/2006	**218**	**170**	**2.08**
Area A	8/18/2006	**219**	**690**	**8.27**
Infusion	8/18/2006	**220**	**430**	**5.37**
Grinding/Cutting	8/18/2006	**221**	**370**	**4.67**
Hull Laminator	8/18/2006	**222**	**920**	**11.75**
Hull Laminator	8/18/2006	**223**	**1200**	**27.47**
Large Part Laminator	8/18/2006	**224**	**1200**	**15.65**
Area G	8/18/2006	**225**	**410**	**6.97**
Hull Laminator	8/18/2006	**226**	**820**	**10.62**
Grinding/Cutting	8/18/2006	**227**	**380**	**5.72**
Large Part Laminator	8/18/2006	**228**	**1100**	**13.67**
Large Part Laminator	8/18/2006	**229**	**900**	**11.66**
Large Part Laminator	8/18/2006	**230**	**900**	**14.54**
Area B	8/18/2006	**231**	**640**	**7.12**
Large Part Laminator	8/18/2006	**232**	**950**	**12.28**
Blank	8/18/2006	**233**	**0**	**0.00**
Large Part Laminator	8/18/2006	**234**	**770**	**10.17**
Blank	8/18/2006	**235**	**0**	**0.00**
Blank	8/18/2006	**236**	**0**	**0.00**
Area F	8/18/2006	**237**	**570**	**7.45**
Large Part Laminator	8/18/2006	**238**	**1000**	**15.56**
Putty and Cutting	8/18/2006	**239**	**410**	**7.10**
Blank	8/18/2006	**240**	**0**	**0.00**

APPENDIX 2

	Date	SampleID	Result (ug/Sample)	Concentration [ppm]
Blank	2/28/2007	101	0	0.0
Blank	2/28/2007	102	0	0.0
Gelcoater	2/28/2007	103	11	0.2
Area F	3/1/2007	104	860	13.8
Small Part Laminator	2/28/2007	105	1400	23.0
Gelcoat Supervisor	2/28/2007	106	0	0.0
Large Part Laminator	2/28/2007	107	1400	18.7
G	3/1/2007	108	880	13.5
Blank	3/1/2007	109	0	0.0
Area B	3/1/2007	110	750	12.7
Large Part Laminator	2/28/2007	111	1600	21.9
Large Part Laminator	2/28/2007	112	1600	21.5
Large Part Laminator	2/28/2007	113	1600	26.4
Hull Laminators	2/28/2007	114	1000	16.0
Hull Laminators	2/28/2007	115	1300	17.6
Gelcoater	2/28/2007	116	940	14.6
Hull Laminators	2/28/2007	117	1500	20.0
Small Part Laminator	2/28/2007	118	1800	24.8
Blank	2/28/2007	119	0	0.0
Large Part Laminator	2/28/2007	120	1600	25.6
Grinding/Cutting	2/28/2007	121	630	9.0
Closed Molding (VIP)	2/28/2007	122	870	13.9
Area E	2/28/2007	123	830	11.2
Area G	2/28/2007	124	560	8.3
Area F	2/28/2007	125	840	11.7
Grinding/Cutting	2/28/2007	126	520	9.7
Small Tanks	2/28/2007	127	340	4.8
Hull Laminators	2/28/2007	128	1400	19.3
Closed Molding (VIP)	2/28/2007	129	520	8.3
Large Part Laminator	2/28/2007	130	550	7.2
Area D	2/28/2007	131	630	8.7
Gelcoat Supervisor	2/27/2007	132	360	6.2
Large Part Laminator	2/28/2007	133	1100	18.2
Area B	2/28/2007	134	720	10.0
Grinding/Cutting	2/28/2007	135	640	10.6

Gelcoater	2/27/2007	136	230	3.9
Blank	2/27/2007	137	0	0.0
Small Part Laminator	2/28/2007	138	1400	18.4
Closed Molding (VIP)	2/27/2007	139	560	8.9
Area A	2/28/2007	140	1100	15.0
Large Part Laminator	2/27/2007	141	1400	18.7
Gelcoater	2/27/2007	142	1500	24.7
Blank	2/27/2007	143	0	0.0
Large Part Laminator	2/27/2007	144	1200	16.3
Hull Laminators	2/27/2007	145	1100	15.7
Closed Molding (VIP)	2/27/2007	146	520	7.8
Hull Laminators	2/27/2007	147	1300	16.9
Area G	2/27/2007	148	670	9.3
Large Part Laminator	2/27/2007	149	490	6.5
Grinding/Cutting	2/27/2007	150	650	10.7
Large Part Laminator	2/26/2007	151	670	9.8
Blank	2/26/2007	152	0	0.0
Area B	2/26/2007	153	460	6.5
Hull Laminators	2/26/2007	154	760	11.9
Area A	2/26/2007	155	1100	15.9
Closed Molding (VIP)	2/26/2007	156	180	2.9
Large Part Laminator	2/26/2007	157	520	7.0
Area F	2/26/2007	158	660	9.5
Small Part Laminator	2/26/2007	159	1100	15.0
Gelcoater	2/26/2007	160	890	13.1
Small Part Laminator	2/26/2007	161	1100	15.7
Large Part Laminator	2/26/2007	162	670	9.6
Small Part Laminator	2/26/2007	163	780	10.4
Grinding/Cutting	2/26/2007	164	460	6.4
Area D	2/26/2007	165	360	5.2
Hull Laminators	2/26/2007	166	850	12.0
Large Part Laminator	2/26/2007	167	940	12.9
Hull Laminators	2/26/2007	168	1000	16.8
Grinding/Cutting	2/26/2007	169	480	6.7
Grinding/Cutting	2/26/2007	170	400	5.4
Hull Laminators	2/26/2007	171	1000	14.0
Area G	2/26/2007	172	350	5.0
Blank	2/26/2007	173	0	0.0
Area E	2/26/2007	174	420	6.1

Blank	2/26/2007	175	0	0.0
Small Tanks	2/26/2007	177	240	3.3
Large Part Laminator	2/26/2007	178	720	10.4
Blank	2/26/2007	179	0	0.0
Large Part Laminator	2/26/2007	180	920	13.1
Hull Laminators	2/27/2007	182	680	14.8
Large Part Laminator	2/27/2007	183	1100	18.5
Area D	2/27/2007	184	660	8.7
Small Tanks	2/27/2007	185	380	4.9
Gelcoat Supervisor	2/26/2007	186	300	5.3
Hull Laminators	2/27/2007	187	1300	17.2
Large Part Laminator	2/27/2007	188	970	15.8
Gelcoater	2/26/2007	189	310	5.4
Area E	2/27/2007	190	780	10.6
Grinding/Cutting	2/27/2007	181	550	7.5
Area B	2/27/2007	191	820	11.2
Small Part Laminator	2/27/2007	192	920	12.4
Large Part Laminator	2/27/2007	193	990	16.1
Blank	2/27/2007	194	0	0.0
Grinding/Cutting	2/27/2007	195	1100	18.6
Small Part Laminator	2/27/2007	196	1600	26.1
Area F	2/27/2007	197	780	10.6
Large Part Laminator	2/27/2007	198	1800	23.3
Small Part Laminator	2/27/2007	199	1400	18.3
Area A	2/27/2007	200	1400	19.4
Hull Laminators	3/1/2007	221	1100	16.9
Area E	3/1/2007	222	720	11.2
Closed Molding (VIP)	3/1/2007	223	190	3.6
Area A	3/1/2007	224	710	11.1
Area D	3/1/2007	225	610	9.6
Small Tanks	3/1/2007	230	500	7.3
Blank	3/1/2007	231	0	0.0
Large Part Laminator	3/1/2007	232	1200	19.6
Large Part Laminator	3/1/2007	233	1000	16.8
Large Part Laminator	3/1/2007	234	1400	21.5
Closed Molding (VIP)	3/1/2007	235	450	8.3
Small Part Laminator	3/1/2007	236	1300	20.4

Large Part Laminator	3/1/2007	237	1300	20.3
Large Part Laminator	3/1/2007	238	1600	24.3
Blank	3/1/2007	239	0	0.0
Large Part Laminator	3/1/2007	240	1400	21.2
Gelcoater	3/1/2007	241	610	10.0
Hull Laminators	3/1/2007	242	1100	16.9
Hull Laminators	3/1/2007	243	1200	18.6
Grinding/Cutting	3/1/2007	244	660	11.4
Grinding/Cutting	3/1/2007	245	640	11.6
Large Part Laminator	3/1/2007	246	500	9.2
Small Part Laminator	3/1/2007	247	1400	21.1
Small Part Laminator	3/1/2007	248	900	13.4
Grinding/Cutting	3/1/2007	249	570	8.6
Hull Laminators	3/1/2007	250	1500	22.2