IN-DEPTH SURVEY REPORT:
STYRENE AND NOISE EXPOSURES DURING FIBER REINFORCED PLASTIC BOAT MANUFACTURING

at

GRADY-WHITE BOATS, INC.
Greenville, NC

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SITE SURVEYED:	Grady-White Greenville, North Carolina
NAICS CODE:	336612 (Boat Building)
SURVEY DATE:	September 26-28, 2007
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DISCLAIMER

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ABSTRACT

A three-day in-depth field survey was performed to assess the occupational exposures of styrene vapors, and to evaluate the effectiveness of the engineering controls currently installed for reducing styrene exposures during a fiberglass reinforced plastic (FRP) boat manufacturing processes. The primary objective of this study was to quantify exposures at a boat manufacturing facility that uses ventilation, low styrene resins, and non-atomizing spraying techniques to reduce emissions and worker exposures during open-mold manufacturing of fiberglass boats. A secondary objective was to assess the noise levels occurring during jobs which involve the use of styrene-based products. The effectiveness of the styrene controls examined in this study was evaluated by measuring styrene concentrations in personal breathing-zone and general-area samples during typical work shifts. The general-area air sample results were below 14 parts per million (ppm) for all of the areas sampled. The lowest personal breathing-zone samples were measured from workers in the closed-mold job category which resulted in a geometric mean styrene concentration of 8.5 ppm. The personal breathing zone samples of workers in the open-molding processes ranged from a geometric mean styrene concentration of 20 ppm for the gelcoaters to 92 ppm for the stringer glass-in workers. One of the twenty-one personal breathing zone samples from hull laminators was higher than 100 ppm. Six of the twelve personal breathing zone samples from stringer glass-in workers were higher than 100 ppm. Three of the personal breathing zone samples higher than 100 ppm were measured from the same worker each day for three consecutive days. A change in work practices could likely reduce these high exposures. Additional recommendations for reducing exposures include increasing ventilation for stringer glass-in workers and hull laminators. The continued use of respirators with organic vapor cartridges is also recommended. Results from workers who are considered to be exposed to both styrene and noise indicated that most of the styrene exposures for this group are equal or below 43 ppm. If any of the workers in this group develop a hearing loss that cannot be explained by their noise exposure, he or she should be referred to his or her physician for further examination.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is part of the Centers for Disease Control and Prevention (CDC) in the U.S. Department of Health and Human Services (DHHS). NIOSH was established in 1970 by the Occupational Safety and Health (OSH) Act, at the same time that the Occupational Safety and Health Administration (OSHA) was created in the U.S. Department of Labor (DOL). The OSH Act mandated NIOSH to conduct research and education programs separate from the standard-setting and enforcement functions conducted by OSHA. An important area of NIOSH research involves measures for controlling occupational exposures to potential chemical and physical hazards.

On September 26-28, 2007, researchers from the Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) conducted an in-depth survey at Grady-White Boats, Inc., in Greenville, North Carolina. The primary purpose of the evaluation was to measure styrene exposures at a boat manufacturing facility that uses modern ventilation, low styrene resins, and non-atomizing spraying techniques to reduce emissions and worker exposures during open-mold manufacturing of fiberglass boats. A secondary objective was to evaluate noise exposures occurring during these operations.

The effectiveness of preventing styrene exposures was evaluated in terms of personal breathing-zone styrene exposures. Personal breathing zone (PBZ) air sampling was used to measure worker exposures to styrene. In addition, styrene concentrations in general-area air were measured at various fixed locations throughout the facility. For this report, effective engineering controls are those that maintain styrene exposures below applicable occupational exposure criteria—the NIOSH Recommended Exposure Limit (REL), the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Value (TLV®), 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 processes. In addition, engineering control and work-practice recommendations will be offered where styrene exposures exceed the NIOSH or OSHA exposure criteria.

Styrene Usage and the Hazards of Exposure to Styrene and Noise

Styrene Usage

The major chemical component of concern in terms of occupational exposures in the fiberglass reinforced plastic (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 resin used at this plant is Maximum Achievable Control Technology (MACT) compliant and contains 33 to 34 percent styrene by weight. Styrene is an essential reactive diluent for polyesters because it reduces the viscosity of the polyester mixture making it thinner and more capable of coating fiber reinforcements allowing the reactive sites on the molecules to interact. As an active diluent, styrene will react in the free-radical cross-linking reaction. Cross-linking is the attachment of two chains of polymer molecules by bridges composed of molecular, in this case styrene, and primary chemical bonds. It produces a solid resin material that is impervious to most solvents, petroleum, and other chemicals found in the marine environment. Since styrene is consumed as part of this reaction, there is no need for removal of the diluents after the part is formed. However, vapors from the application and curing process may pose an inhalation exposure hazard for workers near the process.

Hazards of Styrene, and Exposure Limits

Humans exposed to styrene for short periods of time through inhalation may exhibit irritation of the eyes and mucous membranes, and gastrointestinal effects.[1] 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,[2,3,4] optic,[5,6] and irritant[7] effects when occupational exposures to styrene vapors in air were 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 in sensory nerve conduction velocity 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.[8] 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.[9,10] Styrene has been shown to be a potent ototoxicant by itself, and can have a synergistic effect when presented together with noise or ethanol.[11,12,13,14]

The primary sources of environmental evaluation standards and guidelines for the workplace are: (1) the OSHA PEL;[15] (2) The NIOSH REL;[16] and, (3) the ACGIH® TLV®.[19] Employers are mandated by law to follow the OSHA limits; however, employers are encouraged to follow the most protective criteria. The NIOSH REL for styrene 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.[17] These recommendations are based upon reported central nervous system effects, eye irritation, and respiratory irritation. The OSHA PEL for styrene is 100 ppm for an 8-hour TWA exposure, with a ceiling limit of 200 ppm.[18] The ceiling limit restricts exposures for any portion of the work day. The ACGIH® revised its TLV® in 1997, and recommends styrene be controlled to 20 ppm for an 8-hour TWA exposure with a 40 ppm, 15-minute STEL.[19]

Standards and guidelines for occupational exposure to styrene are also found internationally. 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.[20]

The German Federal Institute for Occupational Safety and Health has an occupational exposure limit value of 20 ppm for styrene.[21]

In February 1996, Styrene Information and Research Center (SIRC) and three other styrene industry trade associations (American Composites Manufacturers Association, National Marine Manufactures 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.[22]

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. Closed molding is exempt from the MACT standard.[23]

Noise Hazards and Exposure Limits

Hazards from exposure to noise include hearing loss from long-term over-exposures and from transient periods of high impulse noise. The OSHA standard for occupational noise exposure, 29 CFR 1910.95, specifies a maximum PEL of 90 decibels, A-weighted (dBA), averaged over an 8-hour time period. The OSHA standard states that exposure to impulse noise (e.g. firearms) should not exceed 140 dB sound pressure level (SPL).[24] The regulation uses a 5 dB exchange rate trading relationship. This means, for example, that if a person is exposed to average noise levels of 95 dBA, the amount of time allowed at this exposure level must be cut in half (to 4 hours) in order to be within OSHA’s PEL. Conversely a person exposed to 85 dBA is allowed twice as much time at this level (16 hours) and is within his daily PEL. The OSHA regulation has an additional action level (AL) of 85 dBA which stipulates that an employer shall administer a continuing, effective hearing conservation program when the 8-hour time-weighted average or TWA exceeds the AL. The program must include monitoring, employee notification, observation, an audiometric testing program, hearing protectors, training programs, and record keeping requirements. The standard also states that when workers are exposed to noise levels in excess of OSHA's PEL of 90 dBA, feasible engineering or administrative controls shall be implemented to reduce workers' exposure levels.

The NIOSH REL for noise (8-hour TWA) is 85 dBA using 3-dB exchange rate trading relationship.[25] NIOSH also recommends that no impulse exposure be allowed above 140 dB peak SPL. The ACGIH® TLV® for noise is 85 dBA (8-hour TWA) with 3-dB exchange rate and 140 dB SPL as a maximum impulse exposure limit[18].

Facility Description

Grady-White's facility, located in Greenville, North Carolina, has 350,000 ft^2 of floor area and employs 360 to 470 people depending on demand. This is the only facility that manufactures Grady-White brand boats. The boat size range is from 18 to 36 feet (ft.) in length. The facility operates one shift per day beginning at 7:00 AM.

The manufacturing portion of the building is split into three production bays. Bay 1 is located on the west side and houses hull lamination. Bay 2, located in the center, is the site of lamination of decks and liners. Bay 3, located on the south side of the facility, includes the closed-mold production of small parts in its southern section, and the open-molding production in its northern section. There are approximately 42 employees working in two of the three bays. A plan view of the controlled-flow ventilation is shown in Figure 1, and a typical cross-sectional side view (of bay 2) is shown in Figure 2. Outside air is supplied from above the lamination process and exhausted perpendicular to the supply region as seen in Figure 1 and 2 below. The arrows shown in Figure 1 and 2 depict the air movement across the hulls, decks, and liners (orange figures). The ventilation system was tested by the engineering firm that designed and installed the ventilation system. The test consisted of ribbon pole and smoke testing for detection of airflow and any potential dead spots.

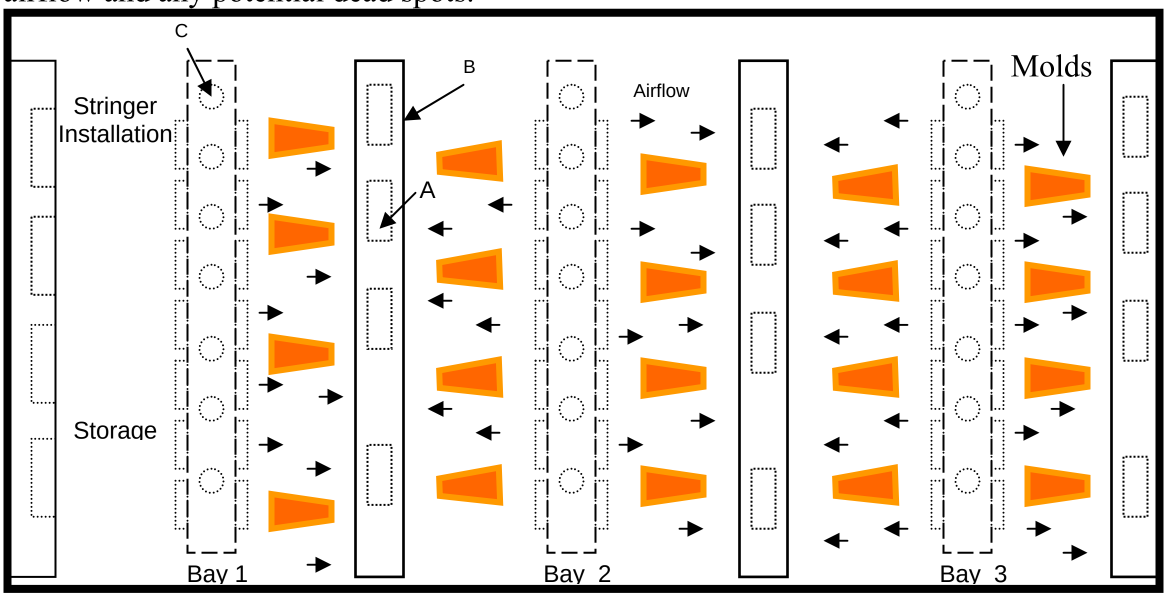

Figure 1: Plan View of Controlled-flow Ventilation installed by Frees Inc.
(A) Vertical takeoffs (B) Filter surfaces (C) Vertical supply duct

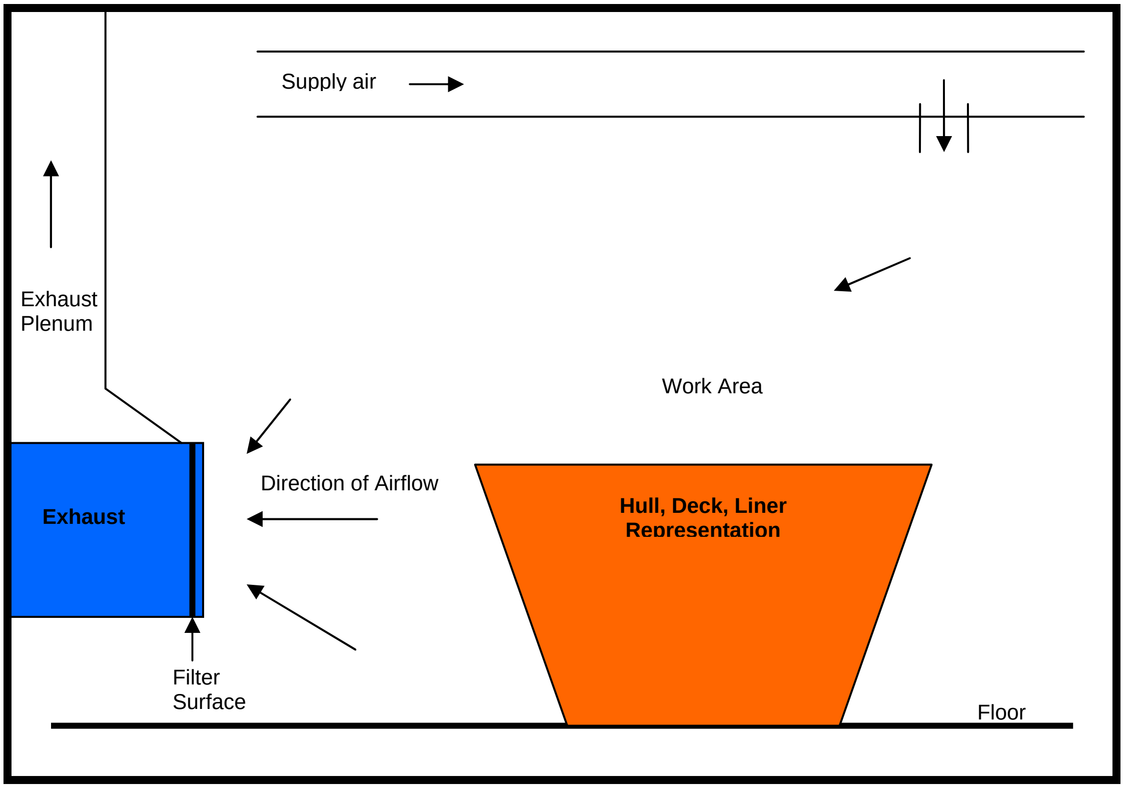

Figure 2: Side View of Controlled-flow Ventilation installed by Frees Inc.

Process Description

The FRP boat manufacturing process mainly used at Grady-White is an open-molding process. Cold-press pneumatic molding (a form of closed molding) is used to fabricate small hatch covers. All of the parts that make up a Grady-White boat are designed using Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) systems. Frame designs were sent directly from the CAD system to the computer-controlled router for output. All boat designs are built in wood or urethane foam prior to production. The fiberglass molds used for production are made from these plugs.

Open Molding

Fiberglass boats are built from glass-fiber reinforcements laid in a mold and saturated with a polyester resin. The plastic resin hardens to form a rigid plastic part reinforced with the fiberglass. The process starts with gelcoating. The mold is sprayed with a layer of gel coat, which is a pigmented polyester resin that hardens and becomes the smooth outside surface of the part. The lamination process begins with the placement of the pre-cut fiberglass mats and is followed by the saturation of resin into the fiberglass mats. All fiberglass mats are hand-laid to provide a uniform laminate structure. The dry mat used is of high porosity to allow resin penetration within the fiberglass structure of the mat during resin saturation (rolling process). Hull molds were rotated sideways during lamination which allows the air to pass through the hull area and then be pulled from behind into the exhaust system. The laminator worked standing approximately twelve inches from the mold. Workers wore half-mask 3M respirators with organic vapor cartridges when stringers (wood reinforcements) were installed and covered with a layer of fiberglass. The orientation of the boat, when laminating, has to be rotated on its side due to the nature of the process and the detailed crevices in the hulls of the boat.

A chopper gun (cuts fiberglass thread into small one inch pieces and sprays chopped glass and resin into the mold) is used for small parts and liners only. The hand-laid fiberglass mats and chopped fiberglass pieces are saturated with resin by a gunner using a MACT–compliant, low-flow, non-atomizing gun. The resin in each part is metered, measured and entered into the computer system so every part contains an optimal glass-to-resin ratio. The saturated resin is then hand-rolled and compressed by the rollers. The laminators and gunners do not wear respirators. Once the fiberglass mats and resin are applied and the desired thickness has been achieved, on some models a stringer system built of treated plywood is cut by a computerized router system and then glassed into the hull while it is still in the mold. The preassembly of the stringer systems occurs in the southwest end of the building adjacent to the closed molding process. All employees in lamination and grinding are enrolled in the hearing conservation program and are required to wear hearing protection.

Closed molding

The cold-press pneumatic molding process is used only for small parts. The process consists of mixing together a resin, a catalyst (methyl ethyl ketone peroxide, or MEKP), and a filler, and pouring the mixture into a mold that has already been loaded with glass reinforcement. The duty of the operator is to meter the resin mixture and pour the resin mixture into the mold. It is then placed into the pneumatic clamp machine and pressed. It takes about five minutes for the process to cure. Two molds are poured per process. Styrene is emitted from the process as the molds are loaded.

Resin Storage Area

There are two 6,000-gallon resin tanks stored outside of the facility. One full tank of resin is used every 4 or 5 days. All of the tanks are jacketed to assure a storage temperature of 75-80 degrees Fahrenheit. The temperature is controlled by water through a shell-and-tube heat exchanger.

METHODS

Air Sampling for Styrene

Personal breathing-zone and general-area air samples for styrene were collected and analyzed in accordance with NIOSH Method 1501 (Hydrocarbons, Aromatic) (NMAM, NIOSH Manual of Analytical Methods).[26] 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 nominal flow rate of 0.3 liters per minute (L/min). The pumps' actual flow rates were calibrated before and after sampling. For personal breathing-zone air 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. In addition, field blank samples were created each day to ensure that the sample media was not contaminated and to account for any variance in sample preparation.

The analyses of the charcoal tube samples for styrene were performed by Bureau Veritas North America, Inc., in Novi, Michigan. 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 milliliter (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 air 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 air sampling. These samples were placed in stationary locations 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 near the liner and deck lamination area, the closed-mold area, small part lamination, and hull lamination areas.

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 in 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 μg/L (mg/m^3) to ppm obtained from: NMAM (NIOSH Manual of Analytical Methods) 1501(Hydrocarbons, Aromatic)

Noise Measurements

In addition to measurements of plant ventilation and styrene exposure, noise exposures were also measured. Eight-hour personal and area noise level measurements were collected using ten Quest Noise Pro dosimeters. A total of eighteen personal full shift measurements were collected during the survey from twelve workers who were also exposed to styrene. Each dosimeter was capable of collecting noise data in one second increments. The dosimeters were set to simultaneously measure the OSHA PEL and the NIOSH REL. The dosimeters conformed to the American National Standards Institute (ANSI S1.25-1997)[27] specifications. Dosimeters were set to "SLOW" response and A-weighting frequency filter. The equipment was calibrated by the manufacturer before the study. Field calibrations checks were conducted before measurements using a Quest calibrator. Data from the dosimeters were downloaded to a personal computer and analyzed using the Quest Suite Professional II software.

STATISTICAL ANALYSIS AND RESULTS

Air Sampling for Styrene

Appendix 1 contains the job title, date, sample ID, result in µg/sample, and concentration in ppm for the samples collected during the three day survey. The sample results were checked for normality using the Shapiro-Wilk test. Subsequently, all data were natural log-transformed for statistical analysis. Personal-sample and area-sample data were analyzed separately.

Data for personal samples were analyzed using the mixed-model procedure with repeated measure options. No statistically significant day-to-day difference was found among the measured personal exposures (p=0.21). However, statistically significant differences in exposure levels were found among job categories (p <0.001). Scheffe's and Bonferroni's adjustment were then used with the mixed model procedure for multiple comparison among job categories. Both Scheffe's and Bonferroni's adjustment methods concluded with the following same results: Workers in the stringer glass-in (geometric mean exposure (gmean) = 92 ppm) job category had significantly higher exposures than the exposures of workers in all other evaluated jobs. Hull laminators (gmean = 43 ppm) had significantly higher exposures than the exposures of liner/deck laminators (gmean = 24 ppm), gelcoators (gmean = 20 ppm) and closed-molding operators (gmean = 8.5 ppm). Statistically significant differences were not found between hull laminators and small parts laminators, or between small parts laminators, liner/deck laminators, and gelcoaters. Closed mold operators (gmean 8.5 ppm) had significantly lower exposures than the exposures of stringer glass-in (gmean = 92 ppm), hull laminators (gmean = 43 ppm), small parts laminators (gmean = 37 ppm), and liner/deck laminators (gmean = 24 ppm).

The nonparametric method of the Kruskal-Wallis Test was used to test differences among measured area sample concentrations of styrene. No statistically significant differences were found among areas (p >0.05). The nonparametric method of the Kruskal-Wallis Test was also used to test for differences among days for each of the four evaluated areas (liners decks, closed molding, hulls, and small parts). No statistically significant differences were found among days (p>0.05) for each of the four areas. Geometric mean, geometric standard deviation, geometric mean 95% confidence limits, and sample size for comparison of personal and area air styrene samples are included in Table I.

Table I: Geometric Mean, 95% confidence intervals, sample size and standard deviation for personal and area air styrene concentrations in ppm

Sample Type	Job Category	Geometric Mean (ppm)	n	Geometric Mean Lower 95% Confidence Interval	Geometric Mean Upper 95% Confidence Interval	Geometric Mean standard Deviation
Area	Area (liners decks)	11	6	7.2	17	1.5
Area	Area (closed molding)	8.7	2	6.0	13	1.0
Area	Area (hulls)	13	6	8.4	21	1.6
Area	Area (small parts)	9.7	5	7.4	13	1.3
Personal	Closed mold operator	8.5	6	6.8	11	1.2
Personal	Gelcoater	20	8	12	35	1.9
Personal	Hull laminator	43	21	34	55	1.7
Personal	Liner/Deck laminator	25	23	17	36	2.4
Personal	Small Parts laminator	37	8	34	40	1.1
Personal	Stringer Glass-In	92	12	73	120	1.5

Noise Dosimetry

Summaries of the personal exposure dosimetry measurements are shown in Table II. The results show the time-weighted average in A-weighted decibels (dBA), and dose (in percentage) of the measurements based on the NIOSH and OSHA criteria for different job titles and tasks.

Table II: Summary results of personal styrene measurements and range of the results of the noise dosimetry for different job titles and job tasks (number of samples indicate cases where both exposures were assessed for the same worker).

Job title or task	Mean styrene concentration (ppm)	OSHA TWA dBA	OSHA Dose %	NIOSH TWA dBA	NIOSH Dose %	n
Hull laminator	43	86.7-89.7	63.5-96.5	91.4-94.4	450-900	4
Closed molding operator	8.5	82.7-87.9	37-75	89.2-92.2	300-534	3
Liner/deck laminator	25	89.2-92	90-119	94.4-95.4	874-1121	4
Small parts laminator	37	89.2-92.4	90-141	94-97.4	797-1741	3
Stringer Glass-In	92	83.3-85.8	40-56	88.4-90.9	250-400	4

DISCUSSION

The results from the personal and area air styrene measurements from this study indicate that mean styrene concentrations were reasonably well controlled and below the OSHA PEL of 100 ppm for the majority of the processes in the plant. However, six of the personal breathing-zone samples measured from stringer glass-in workers and one measurement from hull laminators were higher than 100 ppm. Three of the seven personal samples higher than 100 ppm were measured from a single worker every day for three consecutive days. Two of the personal samples higher than 100 ppm were measured from another worker on two consecutive days. Actual worker exposures were likely much lower since workers in the stringer glass-in area and hull lamination wore half-mask respirators with organic vapor cartridges.

Noise measurements results showed large differences when calculations for time-weighted averages and dose were done using either the OSHA exchange-rate of 5 dB or NIOSH's rate of 3 dB. NIOSH has found that scientific evidence supports the use of a 3-dB exchange rate for the calculation of a TWA for noise.[28] The premise behind the 3-dB exchange rate is that equal amounts of sound energy will produce equal amounts of hearing impairment regardless of how the sound energy is distributed in time.

These workers whose noise exposure measurements were obtained are already in the company's hearing conservation program. Their noise exposures are quite different by job title and task, indicating different needs regarding hearing loss prevention. Workers who are exposed to lower noise levels do not need as much attenuation. In their case, the concern should be to avoid over-attenuation, because it might discouraged the workers from wearing the hearing protection. Details on how to select appropriate hearing protection and on other phases of an effective hearing conservation program can be found in the NIOSH criteria document[28] or part (a) of the OSHA noise exposure standard.[29]

One of the main goals of the study is to evaluate occupational exposures occurring from the closed molding process and to compare the results with results from exposures occurring near open molding processes. However, it was not possible to independently compare the two processes since closed molding and open molding shared the same room and ventilation space. The geometric mean of the personal sample concentrations of the closed molding workers (gmean = 8.5 ppm) was lower than the geometric mean concentrations of any of the area sample collected at other location in the plant and lower than the area sample concentrations for the closed molding area (gmean = 8.7 ppm). Therefore, the personal exposures of the closed molding workers were more representative of the styrene concentrations in the well mixed plant air and apparently not appreciably affected by styrene emissions from the closed molding process. It was not possible to evaluate exposures from the closed molding process independently from other processes taking place in the plant. It is expected that exposures resulting from the closed molding process would be lower than the results measured during this evaluation if the closed molding area did not share ventilation space with open molding processes.

CONCLUSIONS AND RECOMMENDATIONS

At the time of this evaluation, the majority of the measured personal breathing-zone air styrene concentrations were below the OSHA PEL of 100 ppm and NIOSH REL of 50 ppm. However, seven of the personal breathing-zone samples were higher than 100 ppm. Six of the seven personal breathing-zone measurements higher than 100 ppm were measured during the stringer glass-in process. Workers in the stringer glass-in (gmean = 92 ppm) job category had significantly higher exposures than the exposures of workers in all other evaluated job categories. The higher concentrations were likely due to the orientation of the boats and the entrapped air in the hull. It is recommended that additional ventilation be supplied to the hull cavity to reduce worker exposures during the stringer glass-in process. Actual exposures were likely much lower since workers in the stringer glass-in area wore half-mask respirators with organic vapor cartridges. However, additional ventilation should be supplied to the stringer glass-in area to reduce concentrations below 100 ppm. The following recommendations are provided to further reduce styrene concentrations in an effort to help provide a safer and healthier environment.

- Although the majority of the personal breathing-zone samples were below regulatory limits, measurements indicated that personal breathing-zone concentrations were higher than recommended exposure limits such as the 20 ppm TLV® recommended by ACGIH® and European standards such as the 20 ppm occupational exposure level limit values set by the Swedish Work Environment Authority and the 20 ppm exposure limit set by the German Federal Institute for Occupational Safety and Health. Efforts should be made to keep styrene concentrations below recognized exposure criteria that are most protective, whenever possible.

- When possible, workers performing rolling operations should be on the supply side of the ventilation system relative to the gun operator. This will help prevent air currents from directing styrene emissions from the gun directly into the breathing zone of the workers performing rolling tasks.

- The continued use of the organic-vapor charcoal-filter respirators is highly recommended especially for those workers involved in the stringer glass-in process. Personal breathing-zone samples for styrene vapor were reasonably well controlled in the remainder of the plant, outside of the hull lamination area. The ventilation systems effectively controlled worker exposures to styrene vapor in the majority of the plant.

- Regarding the group of workers who are considered to be exposed to both styrene and noise (at levels that triggered their inclusion in the company's hearing conservation program), results indicated that most of the styrene exposures for this group are equal or below 43 ppm. If any of the workers in this group develop a hearing loss that cannot be explained by their noise exposure, he or she should be referred to his or her physician for further examination.

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APPENDIX I

Job Title or Area Sample	Date (2007)	SampleID	Sample Mass (ug/sample)	Concentration (ppm)
Area (hulls)	26-Sep	28	520	10
Area (hulls)	26-Sep	29	1300	26
Area (Liners Decks)	26-Sep	32	760	16
Area (Liners Decks)	26-Sep	33	540	10
Area (small parts)	26-Sep	30	520	10
Area (small parts)	26-Sep	31	430	8.5
BLANK	26-Sep	6	0	N/A
BLANK	26-Sep	7	0	N/A
BLANK	26-Sep	8	0	N/A
Closed Molding Operator	26-Sep	18	370	7.1
Closed Molding Operator	26-Sep	21	410	7.9
Hull Laminator	26-Sep	3	6300	140

Hull Laminator	26-Sep	9	5000	92
Hull Laminator	26-Sep	11	2700	52
Hull Laminator	26-Sep	13	2000	37
Hull Laminator	26-Sep	15	2400	43
Hull Laminator	26-Sep	16	870	16
Hull Laminator	26-Sep	23	3100	59
Liner/Deck Laminator	26-Sep	10	630	13
Liner/Deck Laminator	26-Sep	12	1500	32
Liner/Deck Laminator	26-Sep	14	1200	25
Liner/Deck Laminator	26-Sep	19	1300	26
Liner/Deck Laminator	26-Sep	20	1800	36
Liner/Deck Laminator	26-Sep	24	2300	46
Liner/Deck Laminator	26-Sep	26	3500	69
Small Parts Laminator	26-Sep	1	1500	43
Small Parts Laminator	26-Sep	22	1900	34
Small Parts Laminator	26-Sep	25	1900	36
Stringer Glass-In	26-Sep	2	3900	84
Stringer Glass-In	26-Sep	4	4500	100
Stringer Glass-In	26-Sep	5	5400	120
Stringer Glass-In	26-Sep	27	3200	58
Area (closed molding)	27-Sep	68	430	8.4
Area (hulls)	27-Sep	70	680	14
Area (hulls)	27-Sep	71	640	10
Area (Liners Decks)	27-Sep	72	420	7.4
Area (Liners Decks)	27-Sep	73	430	7.6
Area (small parts)	27-Sep	67	440	8.4
Area (small parts)	27-Sep	69	600	14
BLANK	27-Sep	37	0	N/A
BLANK	27-Sep	38	0	N/A
BLANK	27-Sep	39	0	N/A
BLANK	27-Sep	40	0	N/A
Closed Molding Operator	27-Sep	61	750	12
Closed Molding Operator	27-Sep	66	460	6.8
Gelcoater	27-Sep	41	1400	25
Gelcoaterer	27-Sep	34	1100	37
Gelcoaterer	27-Sep	35	240	5.6
Gelcoaterer	27-Sep	36	470	11
Hull Laminator	27-Sep	42	2300	53
Hull Laminator	27-Sep	43	1900	41
Hull Laminator	27-Sep	44	1800	41
Hull Laminator	27-Sep	45	2000	46
Hull Laminator	27-Sep	48	1400	34
Hull Laminator	27-Sep	49	680	15
Hull Laminator	27-Sep	50	1400	32
Liner/Deck Laminator	27-Sep	53	520	11
Liner/Deck Laminator	27-Sep	54	1600	30.3
Liner/Deck Laminator	27-Sep	55	2500	50.2
Liner/Deck Laminator	27-Sep	56	1800	33.8
Liner/Deck Laminator	27-Sep	57	1300	24.2

Liner/Deck Laminator	27-Sep	58	1900	36.5
Liner/Deck Laminator	27-Sep	59	4300	82
Liner/Deck Laminator	27-Sep	63	200	3.5
Small Parts Laminator	27-Sep	51	1600	35
Small Parts Laminator	27-Sep	62	2100	37
Small Parts Laminator	27-Sep	64	2200	37
Stringer Glass-In	27-Sep	46	4700	110
Stringer Glass-In	27-Sep	47	6400	130
Stringer Glass-In	27-Sep	52	4000	75
Stringer Glass-In	27-Sep	60	4300	74
Area (closed molding)	28-Sep	107	470	8.9
Area (hulls)	28-Sep	101	410	7.9
Area (hulls)	28-Sep	102	970	19
Area (Liners Decks)	28-Sep	105	1100	21
Area (Liners Decks)	28-Sep	106	520	9.6
Area (small parts)	28-Sep	103	410	8.4
BLANK	28-Sep	74	0	N/A
BLANK	28-Sep	75	0	N/A
BLANK	28-Sep	76	0	N/A
BLANK	28-Sep	77	0	N/A
Closed Molding Operator	28-Sep	85	360	10
Closed Molding Operator	28-Sep	108	520	8.2
Gelcoater	28-Sep	78	1500	43
Gelcoater	28-Sep	79	1100	18
Gelcoater	28-Sep	80	1500	25
Gelcoater	28-Sep	81	1500	25
Hull Laminator	28-Sep	82	2000	61
Hull Laminator	28-Sep	83	1400	39
Hull Laminator	28-Sep	84	1300	35
Hull Laminator	28-Sep	86	1800	49
Hull Laminator	28-Sep	91	1800	42
Hull Laminator	28-Sep	92	770	18
Hull Laminator	28-Sep	94	3500	81
Liner/Deck Laminator	28-Sep	88	960	27
Liner/Deck Laminator	28-Sep	89	2400	52
Liner/Deck Laminator	28-Sep	90	1700	41
Liner/Deck Laminator	28-Sep	93	3400	79
Liner/Deck Laminator	28-Sep	95	750	14
Liner/Deck Laminator	28-Sep	96	1100	20
Liner/Deck Laminator	28-Sep	98	280	5
Liner/Deck Laminator	28-Sep	99	210	4.0
Small Parts Laminator	28-Sep	109	2600	44
Small Parts Laminator	28-Sep	110	2000	34
Stringer Glass-In	28-Sep	87	1800	47
Stringer Glass-In	28-Sep	97	4500	80
Stringer Glass-In	28-Sep	100	11000	190
Stringer Glass-In	28-Sep	113	6100	110