

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

AT

**LARSON/GLASTRON INC.
LITTLE FALLS, MINNESOTA**

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Abstract

A survey was performed to assess the occupational exposures to styrene and noise, and to evaluate the effectiveness of engineering controls for styrene in two distinct fiberglass reinforced plastic (FRP) boat manufacturing plants. The primary objective of this study was to quantify the exposures occurring in both an open and closed mold plant and to evaluate the installed engineering controls to reduce styrene exposure. The effectiveness of the styrene controls examined in this study was evaluated by measuring styrene personal breathing-zone and general-area samples during typical work shifts. The ventilation system in Plant 7, the closed mold plant, appeared to be relatively effective for controlling the amount of styrene-area vapors released into the air. Results showed this closed mold system controlled styrene vapor concentrations in the air from 0.14 parts per million (ppm) in areas upwind of the styrene emitting source, to 3.7-12.2 ppm inside the actual Virtual Engineered Composites (VEC) cells. Personal breathing-zone exposures for employees working in the molding areas ranged from non-detected to 20.7 ppm. While these full shift samples were not above the NIOSH Recommended Exposure Level (REL), a comparison between the laminators who spray gelcoat and the loaders who do not, suggests short-term exposures during gelcoat spraying may be a concern. Area samples taken in the resin and gel coat storage rooms showed concentrations, ranging from non-detected to 39.0 ppm. Results for the open mold plant (Plant 6) were markedly different, indicating the installed control systems were not as effective in controlling styrene exposures. The personal breathing-zone exposures, in Plant 6, ranged from 22.8 to 103 ppm with geometric mean exposures ranging from 30.3 ppm (gelcoater) to 82.8 ppm (hull roller). The general-area concentrations measured ranged from 2.2 ppm in the northeast region to 28.7 ppm in the southwest region. Upgrades to the local exhaust ventilation system in Plant 6 should be a priority. The current ventilation system is not working to its maximum potential and thus allowing workers to be exposed to concentrations of styrene vapors above the NIOSH REL and near the OSHA PEL. In Plant 7, the source(s) of the fugitive styrene emissions in the resin and gel coat storage rooms should be identified and controlled. The exposures measured in the gelcoat room are assumed to be a result of agitating, pumping, and handling of gelcoat. Improvements to the local exhaust ventilation systems in the VEC cells should also be considered to address the potentially high short-term exposures. Regarding the noise measurements, all personal and area measurements taken in Plant 6 and 7 were below the OSHA Permissible Exposure Level (PEL) of 90 dBA. The gelcoater and gunner exposures are above the NIOSH Recommended Exposure Level (REL) and OSHA Action Level (AL) of 85 dBA. In a number of cases, measured noise levels indicated that there was great variation in workers' noise exposures. Certain phases of the job are noisier than others or there may be an impact/impulse component to the noise exposure. Sound exposure levels in Plant 6 are on average 2-4 dBA higher than the VEC plant 7 levels (an increase of 3 dB is a doubling of the sound energy). The results of the noise monitoring suggest the need for noise control of tasks that generate excessive exposures in Plant 6. If styrene and noise exposures are not reduced, the audiometric monitoring of employees that are exposed simultaneously to noise and styrene is recommended, as detailed in the ACGIH notes in its Noise Section (ACGIH, 2004).

Introduction

The National Institute for Occupational Safety and Health (NIOSH) is part of the Centers for Disease Control and Prevention (CDC) in the 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 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 controlling occupational exposure to potential chemical and physical hazards.

On September 19-24, 2004, researchers from the Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) conducted an in-depth survey at Genmar Holdings, Inc. Larson/Glastron facility in Little Falls, Minnesota. The primary purpose of this survey was to assess the occupational exposures to styrene vapor in air and to evaluate the effectiveness of engineering exposure-control measures during fiberglass reinforced plastic (FRP) boat manufacturing operations. A secondary objective was to evaluate noise exposures during these operations. Production of fiberglass boats in Plant 7, the closed-mold plant, took place in three self-contained cells using a computer-controlled, automated, closed-mold process called Virtual Engineered Composites (VEC). The open-mold operation, Plant 6, differed greatly from the closed-mold process in terms of both equipment and labor required for production. In both Plants 6 and 7, personal and general area samples were collected for noise and styrene vapor exposures. For this report, effective engineering controls are those that maintain styrene exposures below the occupational exposure limits—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 explains the study methods, results, and provides recommendations for protecting workers more effectively.

Styrene Usage and the Hazards of Exposure to Styrene and Noise

The major chemical component of concern in terms of occupational exposures in the FRP process is styrene. The thermoset polyester resin used at this facility was 32.25% styrene content by weight. Styrene is an important reactive diluent for polyesters because it reduces the viscosity of the polyester mixture making it thinner and more capable of coating fiber reinforcements. Low viscosity also allows the reactive sites on the molecules to interact. Styrene is an active diluent, meaning it will react in the free radical crosslinking 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 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, due to the high volatility of styrene, vapors from the application and curing process may pose an inhalation exposure hazard for workers near the process.

Some of the 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.^{1,2} Styrene has been shown to be a potent ototoxicant by itself, and can have a synergistic effect when presented together with noise or ethanol.^{3,4,5,6} In addition, studies have shown that styrene exposures were linked to central and peripheral neurologic,^{7,8,9} optic,^{10,11} and irritant¹² effects in humans when workplace styrene concentrations were greater than 50 ppm. Finally, there is also evidence concerning the influence of occupational styrene exposure on sensory nerve conduction indicating that 1) 5-10% 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) significant acquired loss of color discrimination (dyschromatopsia) may occur.¹³

Exhaust ventilation, low styrene-content resin, non-atomizing spray equipment, and personal protective equipment have historically been recommended to limit styrene vapor exposures to workers. Recent developments in specific closed molding technologies, however, may also provide protection by reducing process emissions of styrene, and, in turn, workers' exposures.

Facility and Process Description

Open Mold Plant (Plant 6)

Plant 6 produced larger boats of 24 feet or more, and operated one eight-hour shift per day. The facility used an open-molding operation, a labor intensive process which required several employees to work on a single boat at the same time. Approximately 16 employees worked on the deck side, 19 worked on the hull side, and four worked on a small parts line. The small parts produced include hatch and engine covers. Three employees also worked in the gel coat spray booth. In total, approximately 72 employees worked in plant 6; this includes finishing and assembly operations as well as molding.

FRP boat components are built from the outside in. In plant 6, the first step involved the application of the gelcoat, the material that provides the color and appearance of the outer surface of the boat. Prior to each molding operation, the molds were cleaned and then a release agent was sprayed which contained a pigmented gel coat along with an initiator that formed the outside surface of the boat. The gelcoat was sprayed onto the open mold within an enclosed and ventilated booth. After gelcoating, the molds were moved to one of three laminating areas: decks, hulls, or small parts. In each of the laminating areas, a worker (gunner) applied resin and chopped glass fiber to the mold with a chopper gun. The resins are mixed with an initiator to start a cross-linking reaction between the resin molecules. Other workers (rollers) smoothed and compressed the glass and resin using a variety of rollers and flexible blades to saturate the fibrous glass with resin and to remove entrapped air. As a result, the resin hardens to form a rigid fiber-reinforced matrix. Depending on the part, additional layers of glass fiber and resin are added and rolled out until the desired thickness is obtained. In addition, at various stages, glass fiber mats, wood panels, and metal plates were added for additional strength.

Gelcoat Spray Booth

Gelcoat was applied to the mold to provide the outer finish of the boat hull. A barrier coat was applied after the gelcoat to make hulls less permeable to moisture. Both the gelcoat and the barrier coat contained styrene as a major component. In plant 6, (see Figure 2) gelcoat was sprayed by three gelcoaters at two interconnected spray booths. A roll-up door separated the two booths. Make-up air was supplied in the two east corners of both booths and exhausted from the two west corners. When spraying large decks and hulls, the gel coaters sprayed one half of the mold, and then rotated the mold longitudinally on its stand to complete the other half. Small parts were gelcoated in the same booths. The small parts' molds were fastened to carts and moved through the plant manually. When two colors were applied to the decks and hulls, gel coat was applied to the masked mold in the east booth. The mold was then moved to the west booth, the mask was removed, and the second color was applied. The door at the west end was frequently left open while the second color was being sprayed.

Deck Laminating Process

Deck molds were moved from the spray booth located at the west end of the facility to the deck molding area. The deck molding process was operated in two parallel lines; no physical barrier separated the two lines. Molds were on wheeled supports and were moved manually with assistance of a power mule. The first coating of spray core was applied at the beginning of the line, near the exhaust hoods. Spray core is added to strengthen the part and increase thickness, while keeping the part relatively light-weight. Additional layers of chopped glass, glass mat, wood panels, metal plates, resin and spray core were added as the mold moved down the line.

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. These parts were constructed in a similar fashion as the decks. Molds came out of gelcoating and were moved manually on wheeled supports to the small parts area. Layers of resin, chopped glass and glass mat were added to the mold by the gunner then rolled and compressed by the rollers. Compared to the hull and deck molding processes, small parts production used much less glass and resin.

Hull Laminating Process

After gelcoating, the hull molds were moved to the hull molding area. Like the decks, the hulls were fabricated in layers with resin and chopped glass being applied by the gunner. Glass mat, along with wood and metal reinforcements, was also added. The hull molds were mounted on wheeled supports that allow the mold to be rotated about their longitudinal axis. The workers built up a layer on one side of the mold, and then rotated the mold to build the other side. Once the hull had the proper layers of glass and resin added, the mold was moved further down the line where stringers (wood) were added to strengthen hulls. Polyurethane foam was then sprayed at various locations inside the hull.

Ventilation

Supply and exhaust ventilation systems were installed to control occupational styrene exposures to the workers involved in the laminating process. Three make-up air systems were installed in each of the three molding areas: small parts, decks, and hulls. In each area, the design intent was to have the clean make-up air flow from areas of lower concentration to higher concentration. In the hull laminating area, the make-up air system provided clean air down a center aisle between the two lines. The molds were placed with the transoms facing the aisle. The air flow was directed over the transom, through the hull, over the bow, and into the exhaust hood. Gunners (whose activities generated high concentrations of styrene) were directed to work downstream of the rollers, moving from transom to bow. The small parts area adjacent to the hull laminating area had its own makeup air supply unit which flowed past the small parts into the exhaust on the northwest-side of the plant. In the deck laminating area, fresh air was supplied overhead through ducts over the entire length of both lines. Air was exhausted at the west end of the line. The design intent was for air to flow down the entire line.

Closed Mold Plant (Plant 7)

Production of fiberglass boats in Plant 7 took place in three cells using a computer-controlled, automated, closed-mold process called Virtual Engineered Composites (VEC). A fourth cell was used primarily for development purposes. This system used matched-tool molds suitable for injection molding at controlled temperatures, enabling production of hulls, including the entire stinger system and boat floor, to be precise in material proportions, bonding and thickness. Moreover, the VEC process reportedly reduces styrene emissions during lamination by injecting resins and catalyst into a closed mold, limiting the amount of styrene released into the air. In addition to reducing airborne styrene concentrations, the VEC plant incorporates a number of manufacturing advancements such as lifts, in-floor chain conveyors, and overhead power and free conveyors.

Gel Coating

The entire FRP manufacturing process, including gelcoating, took place within each VEC cell. Molds were not transferred from location to location. The VEC cells were designed as a booth; however, they were not completely enclosed. Two molds were located in each cell with two front openings. A ventilation hood was located at the back of the cells opposite of each mold. Each hood measured approximately 14.4 feet wide and 11.4 feet tall. The gelcoating process occurring in the VEC cells was essentially an open molding process. The first step in the VEC process began by applying the gel coat inside the female mold. The ventilation system automatically turned on to a high-airflow setting during this process. The gelcoat sprayer took approximately fifteen minutes to spray the mold and was the only worker within the cell during this operation. While the mold was gelcoated, the other members of the operating crew cut the fiberglass mats that were placed into the mold after the gelcoat cured. The curing process took about thirty minutes. The fiberglass mat was placed in the mold after the gelcoat had cured to the

point that it is tack free (can be touched, etc.), approximately 10 minutes after gelcoating is completed. There was still off-gassing of styrene as the gelcoat continues to cure during the placement of the glass mats.

Lamination

Following gelcoating and curing, the exhaust ventilation system was automatically reset to low speed and pre-cut fiberglass mat was laid into the mold by the operating crew. This dry mat had a high porosity needed to allow resin penetration within the fiberglass structure of the mat during resin injection. The gelcoater and operator worked together to arrange the various types of glass mat into the gelcoated mold, securing them with a heavy duty spray-on adhesive. Layers of fiberglass mat were laid out and then on some hulls, structural pieces were placed in the interior of the hull using a powered overhead conveyer.

Closing the Mold

Each VEC cell was had an automated control center located approximately six feet from the mold. Once the operator inspected the placement of the fiberglass mat, the male mold was lowered, and the two complementary molds were clamped together with pneumatically actuated clamps. The molds were made of fiberglass and supported by a temperature controlled water bath. As a result, the VEC cell had an integral heating and cooling system through which an externally supplied heating/cooling fluid was circulated. Temperature and pressure sensors were located throughout the mold, and measurements were displayed at the control center. The resin was injected under pressure into the mold cavity to saturate and wet the fiberglass reinforcement. The temperature control system allowed the resin to cure in a controlled fashion. Once the resin cured in the mold, the hull was removed from the mold using a vacuum pump-assisted lift.

Gelcoat Handling and Storage

The gelcoat used during the manufacturing process is pumped from an adjacent storage and mixing room. The gelcoat and resin are housed in large 55-gallon drums in separate rooms. When the top of the gelcoat drum is removed, a metal equipment cover is placed on top. This cover houses the agitator and suction hose that transports the gelcoat from the room to the gelcoat guns used by the sprayers. This cover fits over the drum but is not air tight. Styrene emissions occur during the time the drum is being fitted with the cover and during the entire use of the drum. When the drum is pumped down near the bottom to the point that gelcoat cannot be removed via the suction tube, the equipment cover is removed and the gelcoat remaining in the drum is poured into another drum containing the same color of gelcoat. Styrene emissions occur during this process as well. Several drums are used per day and are handled in the same manner. Similar types of procedures are present in chemical storage and handling for both closed molding and open molding.

Ventilation

The ventilation system in Plant 7 was designed to be an integral part of the VEC cell. 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. The air supply came from the southwest and northwest corners of each cell providing air to the main process area and moving the contaminants to the exhaust. As mentioned previously, each VEC cell had a two speed exhaust system (i.e., two different airflow rates); the system was automatically set to the high-airflow during gelcoating.

Respiratory Protection Policy

Larson/Glastron Boats recognized the need to protect employees from potentially hazardous airborne substances throughout the entire plant. A policy administered by the Safety Manager was incorporated to protect employees from airborne hazards. Company policy is to reduce styrene exposures through a combination of exhaust ventilation, administrative controls, and enforcement of a respiratory protection plan. The safety and health representative is responsible for conducting air quality monitoring and enforcing respiratory protection. The air sampling is conducted by OSHA methods and respirators were NIOSH certified and appropriate for the conditions found at the facility. All employees are required to wear respiratory protection when in areas where styrene is present at levels near or above 50 ppm, and are medically certified prior to starting a job that required the use of a respirator. The medical certification consists of a medical history and pulmonary function test, performed by a certified spirometry technician. Before an employee is allowed to wear a respirator with a negative- and/or positive-pressure tight-fitting face piece, the employee is fit tested with the same make, model, and size respirator. An additional fit test is required each time an employee changes the size, style, model, or make, and at least annually thereafter. All employees required to use respiratory protection receive training before beginning a job requiring the use of a respirator. Additional fit testing is conducted annually, or whenever an employee reports changes in their physical condition that could affect respirator fit which ever occurs first. Such conditions include, but are not limited to, facial scarring, dental changes, cosmetic surgery, or an obvious change in body weight.

Safety shoes and safety glasses with side shields were required to be worn at all times in the facility's manufacturing areas as company policy. It was observed that workers complied with respiratory protection arrangements, properly cleaning and storing their respirators. In Plant 6, workers wore respirators when molding, spraying gel coat, and applying spray core. In Plant 7, where styrene controls are assumed to be more effective, employees regularly wore respirators during gelcoating operations only. All workers in both plants participated in stretching exercises before the start of their shift. At around 5:45 a.m. the entire crew assembled at designated locations in each plant to do hand and upper body stretches.

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 (Anasorb CSC, Coconut Charcoal). 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 a 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 in each plant and on each shift, 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 Datachem Laboratories Inc. in Salt Lake City, UT. The samples were analyzed using a Hewlett-Packard Model 5890A gas chromatograph equipped with a flame ionization detector. The desorption process took thirty minutes in 1.0 milliliter of carbon disulfide containing 0.5 micro-liters (μL) of n-octane/mL as an internal standard. The column contained a 30mm x 0.32mm fused silica capillary coated internally with 1.0 micro-meter (μm) of DB5-ms set at 40°C for three minutes and then up to 70°C for 10 minutes at a rate of 5°C per minute. The limit of detection and limit of quantification for styrene for this sample set was 0.004 and 0.01 mg per sample 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 systems performed, and to assess the spread of the styrene vapor throughout the facility. In Plant 7 area samples were placed in production cells 1, 2, and 3 along the face of their corresponding local exhaust vent. Additional samples were collected upwind of the process in front of cell 4 and in between cells 1 and 2. Resin and gel coat storage areas were sampled due to the high volume of styrene contained within the closed spaces. Even though resin mixtures were contained within closed systems, high concentrations were detected using detector tubes in a previous walk-through visit to this plant. Specific locations of the area samples are shown in Figure 1. The symbol “*” in Figure 1 below denotes the location of a local exhaust vent (LEV).

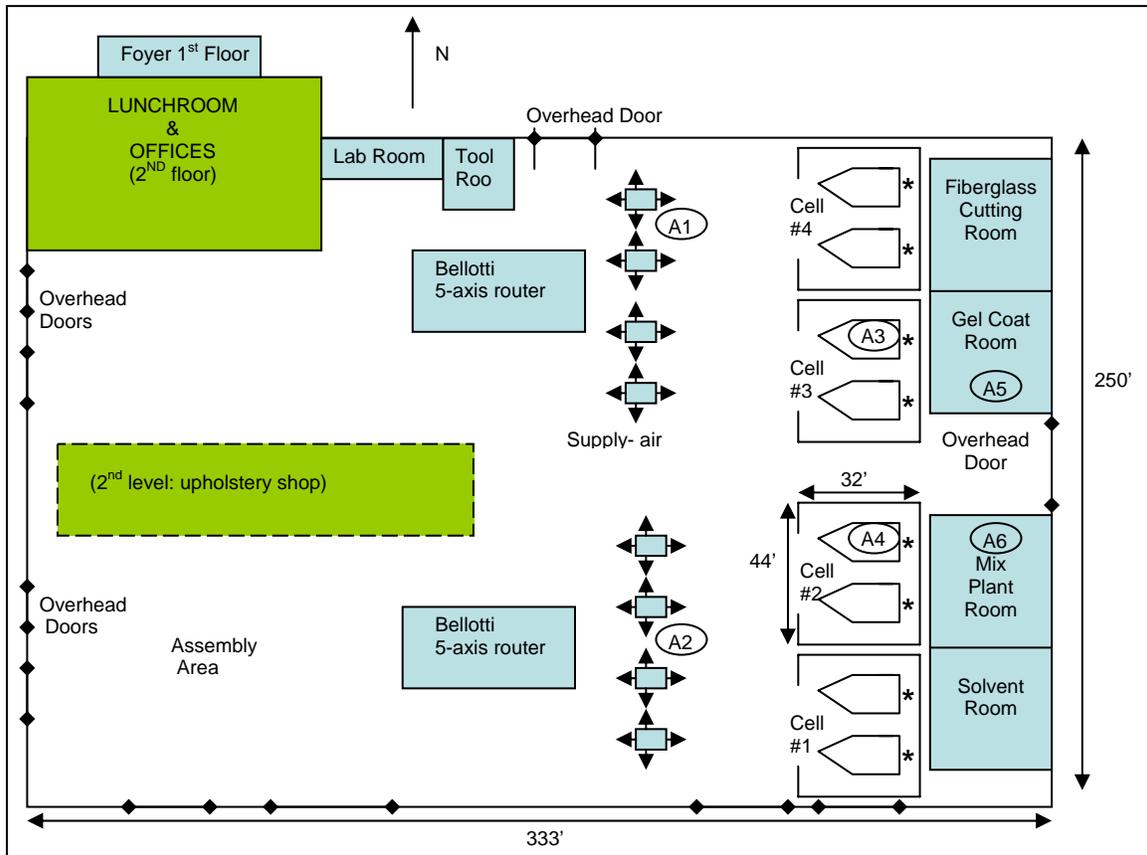


Figure 1: Location of Area Samples in Plant 7

Personal breathing-zone samples were placed on each of the gelcoat sprayers working in a production cell. Gelcoaters perform the bulk of the gelcoating; laminators may perform some of the gelcoating in addition to cutting fiberglass mats. These two groups of workers are referred to as “sprayers” in this report. A total of three sprayers along with the nine people from the operating crew were sampled during each shift. The other job titles include the loaders (load fiberglass mat into the cells), floaters (float between loaders, laminators, etc. depending on the need), and operators (operate control panel and also assist the loaders and floaters). These groups are referred to as “operators” in this report. Usually two members of the operating crew laid out the fiberglass mats once the mold had been prepared by the gelcoater. Normally the gelcoater started an hour before the rest of the crew to prepare the cell and spray the gelcoat.

In addition to the evaluation of the closed molding process, this site provided the opportunity to assess a large open-molding operation located in Plant 6. Thus, special attention was given to Plant 6 to understand the operations, tasks, and control strategies associated with the occupational exposures to both styrene and noise. Five laminating lines (two hulls, two decks, and one small parts) were operated at a time, and each of these lines was sampled similarly. Area samples were placed as shown in Figure 2. Personal samples were distributed through the areas of the production plant where styrene

was used. In the spray booth, all of the gel coaters' were sampled throughout the day. Gunners using fiberglass chopper guns that applied the styrene-containing resin were sampled due to their close proximity to the resin. One gunner working in each of the three molding areas was sampled as well as the first and second layer rollers.

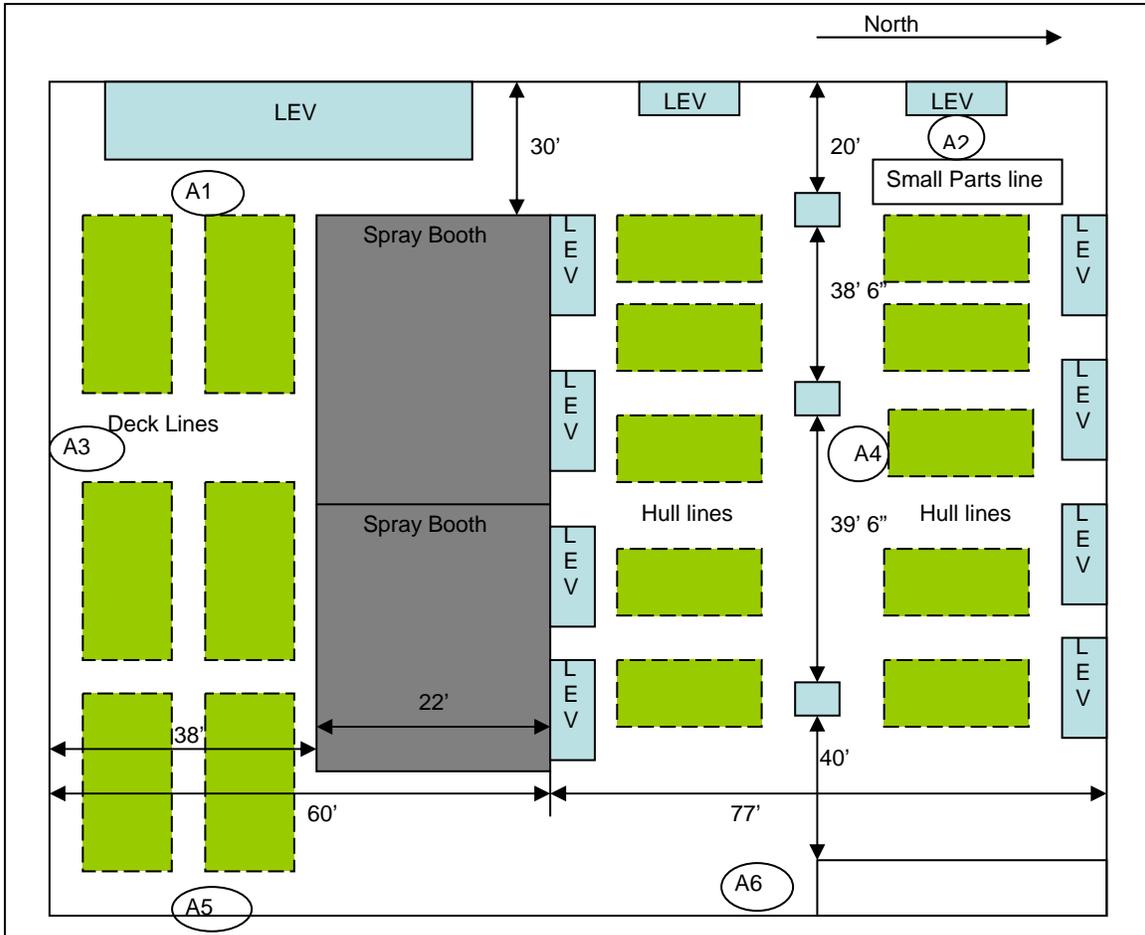


Figure 2: Location of Area Samples in Plant 6

Once the sample results were received from the analytical laboratory, the styrene breathing zone concentrations were calculated using Equation 1.

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

Where,

C = styrene concentration, ppm

m=mass of styrene per sample, µg

V =volume of air sample, L

Note: 4.26 is a constant for styrene obtained from: 1501(Hydrocarbons, Aromatic) (NMAM, NIOSH Manual of Analytical Methods)

The limit of detection (LOD) for styrene for this sample set was 0.004 mg per sample. Consequently, some of the sample results were reported by the laboratory as non-detected. To more accurately estimate mean exposures, these non-detected samples should be included in the calculations, but an estimate of the value of these samples was needed. An accepted method is given in Equation 2. The statistical terminology for these results is known as censored data, i.e., nonzero values which cannot be measured but are known to be below some threshold.¹⁴ Samples that were non-detectable were estimated using Equation 2.

$$\ell \approx \frac{LOD}{\sqrt{2}} \quad (2)$$

Where,

LOD = limit of detection

ℓ = best estimate for non-detectable value, value between 0.0 and *LOD*

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 eleven Larson-Davis 705+ and 706 Type 2 dosimeters. A total of fifty-six personal and area measurements were collected during the survey. 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) specifications.¹⁵ Dosimeters were set to “SLOW” response and A-weighting frequency filter. The equipment was calibrated by the manufacturer before the study. Field calibrations were conducted before and after measurements were taken using a Larson-Davis CAL250 calibrator. Data from the dosimeters were downloaded to a personal computer and analyzed using the Larson-Davis 824 Utility 3.0 and BlazeTM software.

Evaluation Criteria

The primary sources of environmental evaluation standards and guidelines for the workplace are: (1) the OSHA Permissible Exposure Limits (PEL),¹⁶ (2) The NIOSH Recommended Exposure Limits (REL),¹⁷ and (3) the American Conference of Governmental Industrial Hygienists' (ACGIH[®]) Threshold Limit Values (TLV[®]). 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 is 50 ppm time weighted average (TWA) (meaning the limit is for 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.¹⁸ 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.¹⁹ 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 to be controlled to 20 ppm for an 8-hour TWA exposure with a 40 ppm, 15-minute short-term exposure limit (STEL).²⁰

In February 1996, the 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 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.²¹

Larson/Glastron has based its compliance status in accordance with the industry's voluntary agreement with OSHA in accordance with the following specifications: for concentrations below 50 ppm no respirators will be worn and concentrations between 50 and 100 ppm respirators are acceptable.

The U.S. EPA regulates the gelcoating process occurring in Plant 7, closed mold, as essentially an open molding process. The Minnesota Pollution Control Agency (MPCA) has established the emission factor gelcoating based on the accepted open molding factors with a slight modification. The MPCA's emission factor takes into account that the gelcoat has not completely cured before the fiberglass is placed in the mold and that the mold is closed.

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 (i.e. firearms) should not exceed 140 dB sound pressure level (SPL).²² 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 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. 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.

Results

Air Sampling for Styrene

Results from the personal breathing-zone and general-area air samples are presented in Appendix A, Tables A1-A3. These tables 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, sample time, volume, and concentration. The distribution of the samples was checked for normality using the Shapiro-Wilk test. The results of this test suggested the data were log-normally distributed, and all data were log-transformed when subsequently analyzed statistically. The sample data for Plant 6 and Plant 7 were analyzed separately. Personal breathing-zone styrene samples were grouped according to each specific job class based on the similarity of the tasks involved. General-area samples were grouped based on the location and distance from the styrene sources. The calculated geometric means (measure of central tendency), standard deviations, and lower and upper 95% confidence limits are shown in Tables 1 thru 4.

Table 1. Results of full-shift air sampling for styrene, Plant 6, Personal Breathing-Zone Samples					
Job Title	Lower 95% Confidence Limit [ppm]	Geometric Mean [ppm]	Upper 95% Confidence Limit [ppm]	Number of Samples	Geometric Standard Deviation
Gelcoater	26.11	30.25	35.04	12	1.26
Gunner Deck	64.55	77.88	93.96	4	1.13
Gunner Hull	30.27	48.18	76.68	4	1.34
Gunner Small	23.45	38.11	61.95	4	1.36
Roller Deck	55.1	72.7	95.92	6	1.3
Roller Hull	59.16	82.77	115.8	4	1.23
Spray Core	11.22	45.67	185.95	3*	1.76

Table 2. Results of full-shift air sampling for styrene, Plant 6, General-Area Samples					
Location of Area Sample	Lower 95% Confidence Limit [ppm]	Geometric Mean [ppm]	Upper 95% Confidence Limit [ppm]	Number of Samples	Geometric Standard Deviation
North Center	15.97	25.42	40.47	4	1.34
Northeast	0.12	2.23	41.75	4	6.3
Northwest	9.72	15.38	24.32	4	1.33
South Center	10.5	12.95	15.97	3	1.09
Southeast	3.2	5.11	8.16	4	1.34
Southwest	21.97	28.65	37.36	4	1.18

Table 3. Results of full-shift air sampling for styrene, Plant 7, General-Area Samples					
Location of Area Sample	Lower 95% Confidence Limit [ppm]	Geometric Mean [ppm]	Upper 95% Confidence Limit [ppm]	Number of Samples	Geometric Standard Deviation
Gelcoat Room	6.98	12.2	21.34	8	1.95
LEV filter 1	1.23	3.62	10.66	5	2.39
LEV filter 2	3.08	12.16	47.91	3	1.74
LEV filter 3	1.34	3.63	9.84	8	3.3
Upwind of Cell	0.11	0.14	0.18	16	1.64
Resin Mix Room	1.75	8.35	39.93	8	6.5

Table 4. Results of full-shift air sampling for styrene, Plant 7, Personal Breathing-Zone Samples					
Job Title	Lower 95% Confidence Limit [ppm]	Geometric Mean [ppm]	Upper 95% Confidence Limit [ppm]	Number of Samples	Geometric Standard Deviation
Sprayer	4.97	7.72	12.02	24	2.85
Operator	0.52	0.84	1.37	29	3.61

The figures that follow (Figures 2-6) show the error about each corresponding full-shift geometric mean. These figures also show the NIOSH, OSHA, and ACGIH exposure criteria. For personal breathing-zone samples in Plant 7 two job functions, gelcoater and laminator, were grouped together under one category (sprayer) in order to keep the data analysis appropriately organized. The other category (operator) includes the loaders, floaters, and operators. In Figure 5 the specific job titles found in Figure 4 were regrouped and averaged together to display all of the personal breathing sampled in Plant 6.

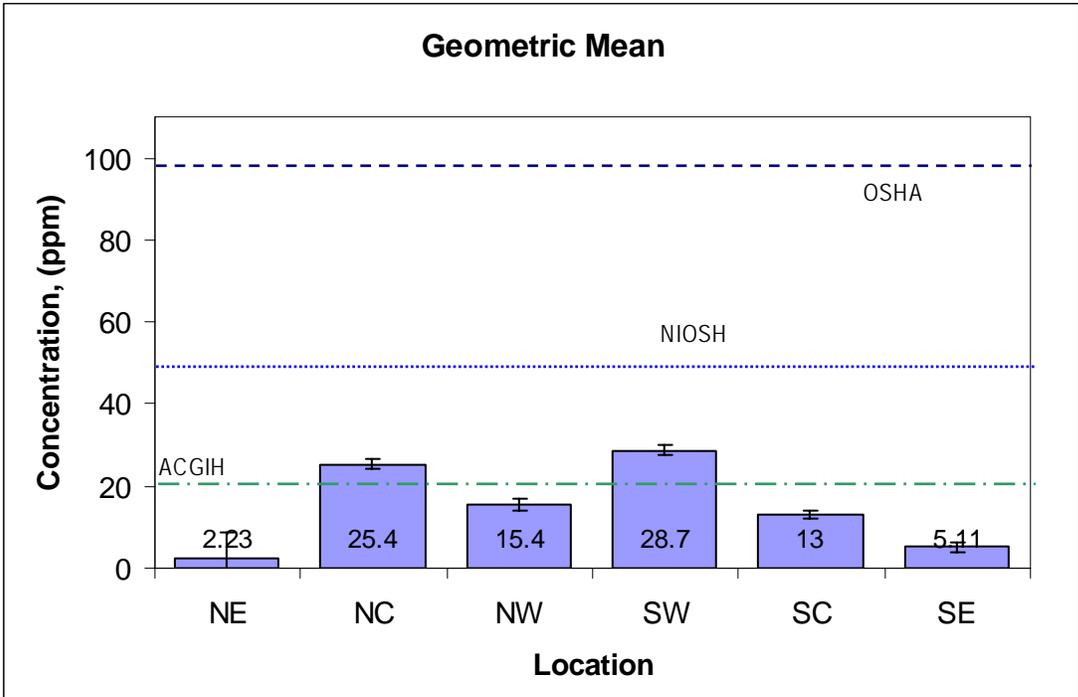


Figure 3: Plant 6 General-Area Sample Results

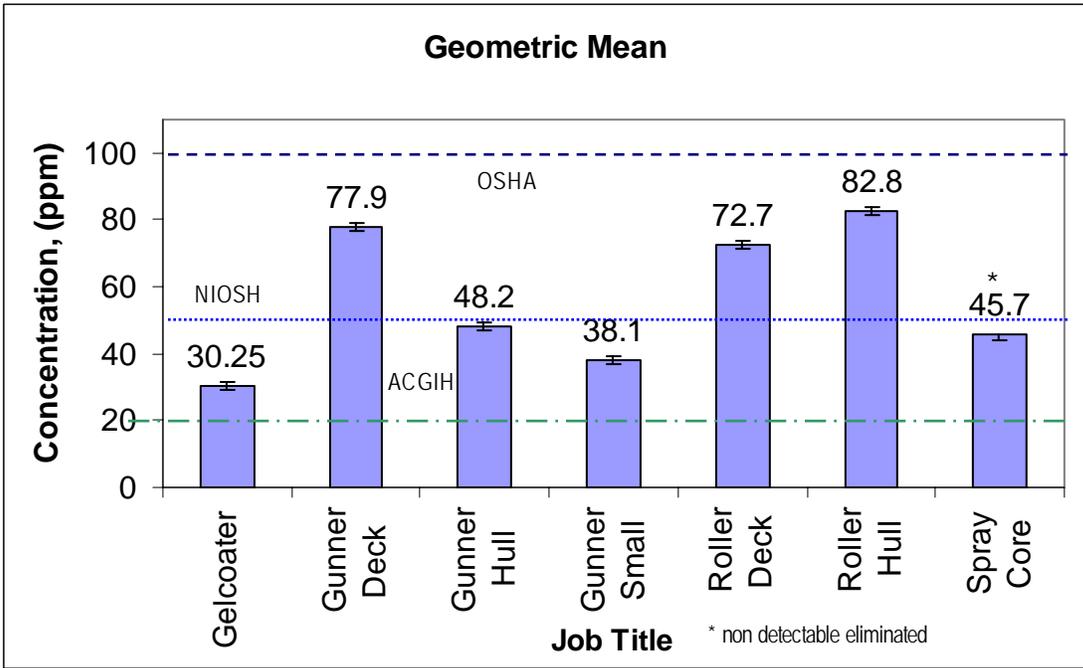


Figure 4: Plant 6 Personal Breathing-Zone Sample Results

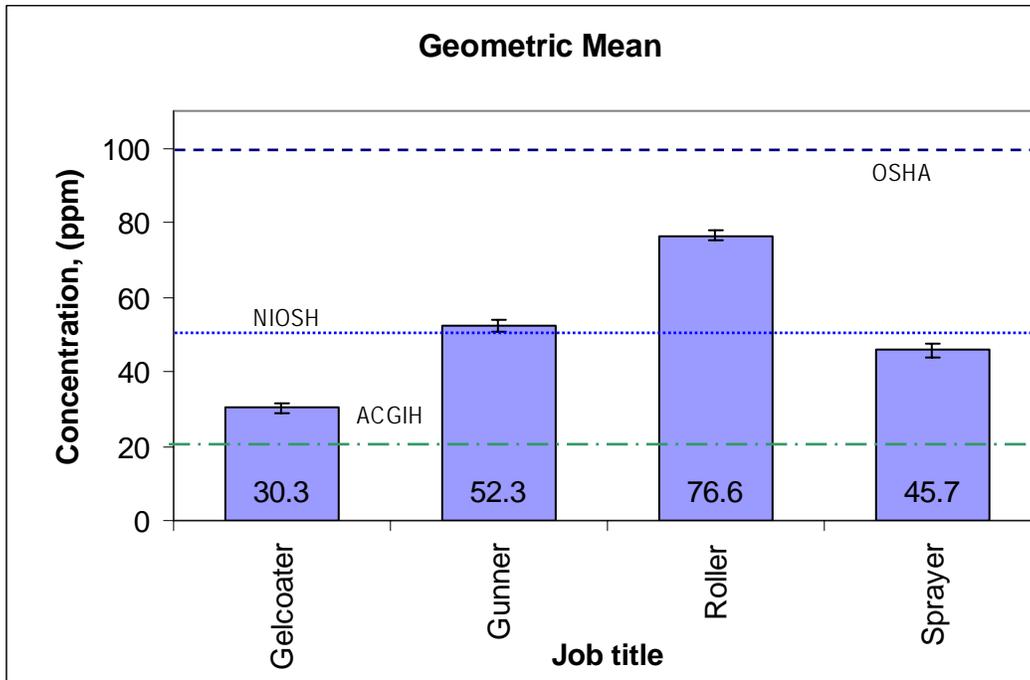


Figure 5: Plant 6 re-grouped Personal Breathing-Zone Sample Results

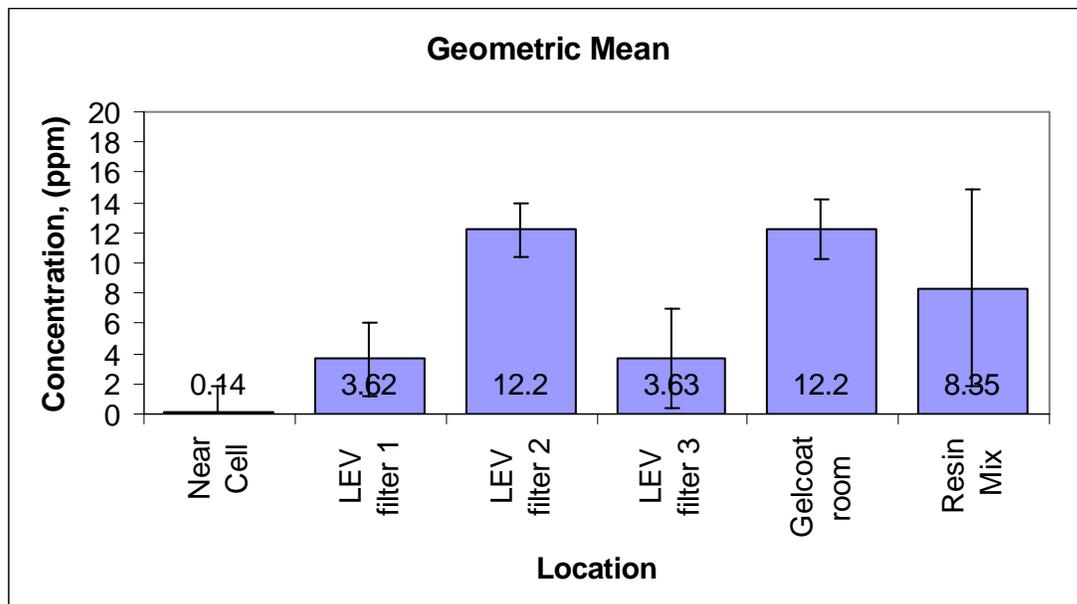


Figure 6: Plant 7 General-Area Sample Results

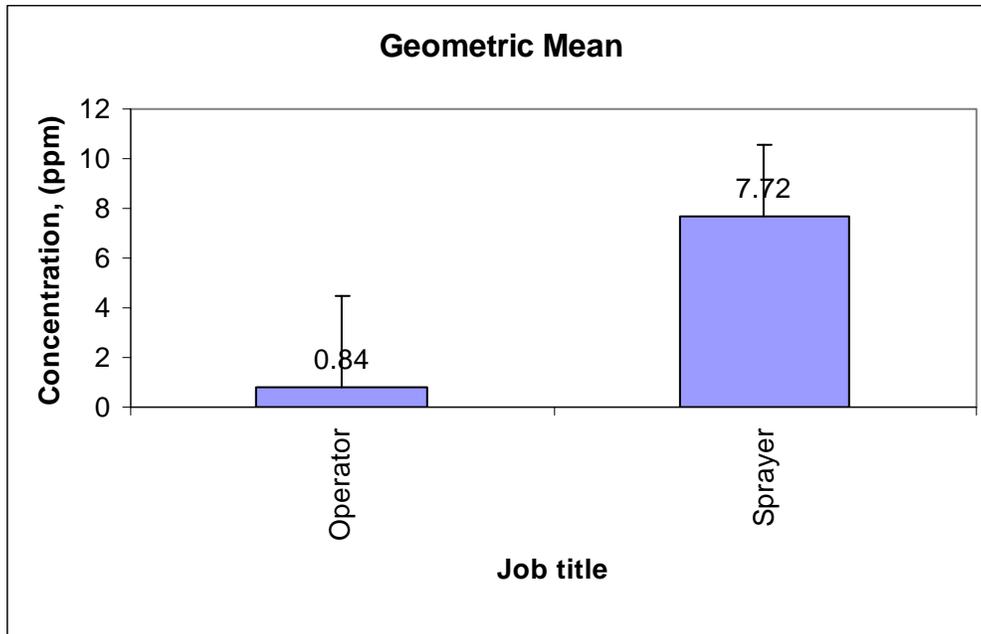


Figure 7: Plant 7 Personal Breathing-Zone Sample Results

A one-way analysis of variance (ANOVA) technique followed by Tukey’s multiple comparison procedures were used to test for statistically significant differences in exposures and concentrations among job categories and area locations. Results from the ANOVA ($p \leq 0.0001$) for the Plant 6 personal samples indicate that the hull rollers, deck gunners, and deck rollers have statistically significant higher exposure levels than the small parts gunner and gel coater. Results of the ANOVA ($p \leq 0.002$) for area samples indicate that the concentrations in the northeast area of the Plant 6 (geometric mean = 2.23, GSD = 6.30) was statistically significantly lower than that of the southwest, north center, and northwest. No statistically significant differences were found among the northeast, south center, and southeast areas. For Plant 7, the personal breathing-zone styrene samples were categorized into two groups: sprayers and operators. The ANOVA results ($p \leq 0.0001$) indicated that the sprayer (geometric mean = 7.72, GSD = 2.85) has statistically significant higher exposure than the operator (geometric mean = 0.84, GSD = 3.61). Results of the ANOVA ($p \leq 0.0001$) for the area samples in Plant 7 indicated that concentrations upwind of VEC cells 1 and 3 (geometric mean=.14, std=1.64) were statistically significantly lower than any of the other locations.

Notes on Statistics

The spray core sprayer breathing-zone sample in Plant 6 on day 4 (September 21, 2004) appeared to be anomalous when compared to other personal breathing-zone samples of the spray core operator for the other sampling days (the samples in this category were taken on the same person each day). The personal breathing-zone concentrations for the spray core sprayer were non-detectable, 86.5, 37.2 and 29.6 ppm. It is apparent that the non-detectable value is exceptionally lower than other samples. While a specific reason

for the sample irregularities could not be determined, the investigators believe that the most appropriate approach would be to eliminate this data value from the set for calculating the geometric mean, standard deviation, and lower and upper confidence limits. The geometric mean concentration with non-detectable value removed is 45.67 ppm (as illustrated in Fig. 4).

Ventilation Assessment – Plant 6

Observations from use of smoke tubes and hot-wire anemometer measurements in the hull molding area showed that the ventilation systems were not performing as intended. Ideally, air in this area would move from the center isle to the sides, where the exhaust hoods were located. This was not found to be occurring, likely due to three causes. First, there appeared to be a slight movement of air upward, likely caused by heat generated from the curing resin. Second, air flow into the exhaust system appeared to be inadequate. In some cases, exhaust inlets were blocked by various objects such as boxes and supply cabinets. In other cases, the exhaust system was either not designed or not operated to provide the appropriate exhaust flow. Finally, the air supply system serving the hull molding area had been modified recently to allow the production of a larger model boat. These modifications prevented make-up air from being supplied effectively to the molding lines. Consequently, the ventilation control system did not appear to be achieving the level of control that was intended.

In the small parts molding area (located in the extreme northwest corner of Plant 6) air appeared to move away from the workers toward the exhaust. However, much of this air passed above the exhaust hoods due to inadequate exhaust flow, and was likely re-entrained back into the plant. Air movement within this area appeared to be due to supply flow rather than exhaust.

In the deck laminating area, smoke tubes showed that, while air generally moved down the line toward the exhaust hoods, there was substantial mixing between the two lines. This reduced the effectiveness of the administrative control limiting work downstream of each line. Under this administrative control, laminating activities could occur on one line near the exhaust hoods while a different deck was being laminated on the other line further upstream. Because of the mixing of air between the two lines, the upstream activities on one line would likely have an adverse impact on the occupational exposures downstream on the other line.

Ventilation Assessment – Plant 7

Hood face velocity measurements were taken at each cell in order to determine how the supply and exhaust systems were performing in VEC process. Each ventilation hood face was 83 ft², and was protected by filters at the face of the hood. A TSI Velocicalc® (TSI, Incorporated, Shoreview, MN) was used to measure the velocities. The hood face was divided into a grid of 30 squares measuring 20 inches by 20 inches, and the Velocicalc sensor was placed at the approximate center of each square; each velocity was measured and stored. Average velocities were calculated and are shown in Table 5, along with estimated flowrates.

Table 5: Results of Plant 7 Ventilation Assessment

VEC Cell No.	North or South Mold	Local Exhaust Ventillation System: Normal or High Flow rate	Average of 30 face velocity measurements [ft/min]	Estimated Volumetric Airflow rate [ft ³ /min]
		Normal	121*	10,000
1	N	High	293	24,400
		Normal	131*	10,900
	S	High	275	22,900
		Normal	128	10,700
2	N	High	250	20,800
		Normal	115	9,580
	S	High	249	20,800
		Normal	126	10,500
3	N	High	242	20,200
		Normal	137	11,400
	S	High	234	19,500
		Normal	133	11,100
4	N	High	249	20,800
		Normal	72-103**	6,000-8580
	S	High	257-277**	21,40-23,100

***Indicate a dirty filter**

****No filter. Therefore, velocity profiles were uneven and highly variable**

Noise Exposure Results

Summaries of the personal and area exposure dosimetry measurements are shown in Table 6. The results show the average and standard-deviation of the measurements based on the NIOSH and OSHA criteria. The overall noise exposure levels between the two plants are shown in Table 7.

Table 6: Personal and Area Dosimetry Results

Job Description	NIOSH		OSHA	
	TWA (dBA)	Dose (%)	TWA (dBA)	Dose (%)
Loader	81.27 ± 4.1	68 ± 83	73.4 ± 5.1	13.1 ± 11.5
Gel-coater	86.1 ± 2.8	157.3 ± 99.6	80.4 ± 3.4	29.6 ± 15.3
Laminator	83 ± 1.8	68.3 ± 31.5	78.7 ± 2.8	22.4 ± 8.5
Gunner	88 ± 0.6	200.6 ± 28.6	85.9 ± 0.9	57.1 ± 7
Area – Hull	83.7 ± 2.4	81.9 ± 41.6	81.8 ± 4.2	43.9 ± 30.5
Area – Assembly	82.6 ± 0.5	57.3 ± 7.3	79.8 ± 1.9	25.1 ± 7.7

Table 7: Total noise exposure-- VEC vs. Plant 6

Plant	NIOSH		OSHA	
	TWA (dBA)	Dose %	TWA (dBA)	Dose %
VEC	83.3 ± 3.7	95.5 ± 89.7	77.6 ± 5.1	22.5 ± 15
Plant 6	85.4 ± 2.5	126.5 ± 69.5	81.9 ± 3.4	37.5 ± 19.3

Discussion and Conclusions

Plant 6 (Styrene Exposures)

Of the three groups of gunners sampled (decks, hulls, and small parts), the deck gunner had the highest mean exposure, 77.9 ppm. The hull gunners' and small parts gunners' styrene exposures are 61.9% and 48.9% of the deck gunners' exposures, respectively. This difference was likely due to the geometric shape of the decks compared to the hulls and small parts. The hulls and small parts tend to have simpler shapes. The decks are very complex shapes, requiring the gunner to twist into positions where his/her breathing zone was upwind from the spray gun. In comparison, the small parts gunner had the lowest geometric mean exposure (38.1 ppm) likely due to close proximity of the exhaust ventilation system. It should also be noted that the resin application time for the small parts appeared to be less than that of the decks and hulls thus yielding a lower exposure level. The hull gunners' geometric mean exposure concentration was 48.2 ppm. While the small parts gunner and the hull gunners' geometric mean exposures were below the 50 ppm NIOSH REL, some of the individual measurements for all three groups of gunners exceeded the NIOSH criteria as well as the ACGIH TLV of 20 ppm.

The gel coaters' geometric mean styrene exposure was 30.3 ppm. Although this concentration is below the NIOSH REL it is near the ACGIH TLV of 20 ppm. All gelcoating was performed in a ventilated booth; because of the configuration of the booth, work practices of the gelcoaters could not be easily observed, and their contribution of work practices to the exposures is not known. From the data, it can be concluded that the ventilation system currently installed does not ventilate the spray booth adequately; an improved more efficient ventilation system would yield lower breathing-zone exposures.

The geometric mean concentration for the hull roller was 82.8 ppm, the highest mean exposure in this survey. Rolling is a laborious task, requiring the worker to stand over the wetted mold rolling the resin and fiberglass into the proper form. A major contributor to these exposures involves the positioning of the roller relative to the gunner. It is extremely important that rollers remain upwind of the gunners, which was not the case in many instances. The company does have administrative controls in place requiring rollers to position themselves upwind of the gunners during the laminating process. However, process conditions did not always allow this positioning to occur. In addition, the ventilation system in the hull molding area did not appear to be working effectively. Recent modifications to the current ventilation system in the hull area were made by the company to accommodate production of larger boats. These modifications changed the way air was supplied by the make-up air system. Combined with the exhaust systems that were either blocked or not operating properly, the ventilation control systems were not performing effectively.

The mean exposure concentration for the deck rollers was 72.7 ppm 12% lower than the mean exposure concentration for the hull rollers. Although there were two lines in the deck-molding area (as described in the *Process Description* section of this report), the single ventilation system allowed air from the two lines to mix, potentially increasing the exposures of one group of rollers from the activities of a different production team.

Area samples were taken in six different locations in Plant 6. These samples show how the styrene disperses throughout the plant, as seen in Figure 6. As expected, higher concentrations were found in the molding production areas (illustrated in Fig. 1 as A-1 thru A-4) where the resin was sprayed. In the deck production area, the exhaust was located in the southwest region of the plant, and all of the styrene generated upstream from the two production lines travels to the southwest region where the highest general-area concentration measured was 28.65 ppm. While it appeared that the ventilation systems effectively prevented the dispersion of styrene vapor into the non-laminating areas of the plant, the systems' effectiveness at controlling concentrations within the molding areas was limited. In the hull and small parts areas, smoke tube tracings showed that the air was not moving as expected. Several items (boxes, tool chests, cabinets) were blocking the exhaust vents and inhibiting the proper air flow to the exhaust. Administrative controls should be established to maintain the areas around the exhaust hoods free of obstructions that may block proper air flow.

Plant 7 (Styrene Exposures)

The styrene concentrations detected in Plant 7 were relatively low, as expected. The sprayers' and operators' geometric mean exposures were 7.72 ppm and 0.84 ppm respectively. Even though the exposure of the sprayer was 7.72 ppm, the amount of time each sprayer spent spraying each boat was approximately 15 minutes, and he/she sprayed about 6 or 7 boats per day. The operators spent a limited time near the cells. They assisted the laminators, but were not near the area when any spraying was occurring. While the sprayers' exposures were not above the various exposure criteria, it is clear that the sprayers' exposures were increased by the spraying activities they performed. It is suspected that the sprayers' styrene exposures that were measured at the VEC cells are associated with gelcoating—the higher concentrations are assumed to be occurring during the gelcoating process and the lower exposures are associated with the placement of the fiberglass mat. However, the eight-hour TWA sampling does not differentiate between different times; hence the TWA is taken from the total sampling time. An estimate of the sprayers' short-term exposures can be calculated by making several assumptions: 1) the sprayers apply gelcoat on 6 hulls per 8-hour shift; 2) the sprayer spends 15 minutes spraying the hull; and 3) the sprayer's exposure during non-spray activities equals operator's exposure during the normal 8-hour shift. The estimated short-term exposure for the sprayer based on the highest sampled concentration is 37.5 ppm. This is only an estimate; however, the result suggests that the sprayers may be approaching the ACGIH STEL of 40 ppm for a 15-minute period. It should be noted that respirators were worn by anyone spraying, and the vent system was set on high during the spraying. Geometric mean area concentrations ranged from 3.62 to 12.2 ppm at the face of the exhaust hood. The geometric mean concentration for the area sample further upstream of the VEC cells

was 0.14 ppm. This suggests that the local exhaust ventilation systems for the VEC cells were effective in limiting the dispersion of styrene vapor throughout the plant.

The VEC system is a closed system, however, the resin and gelcoat storage and mixing processes are not completely closed. The data suggests that there is a styrene emission source (leakage is occurring) in the resin and gelcoat rooms. The geometric mean styrene concentration in the gelcoat room was 12.2 ppm, while in the resin mix room it was 8.35 ppm. The large overhead door in the resin mix room was open during much of these sampling periods, likely diluting the styrene concentration. These concentrations, while not in excess of the exposure criteria, should be of concern. There are instances when system opening does occur. Larson/Glastron suspect that the exposures measured in the resin room result from the periodic opening of the top of the shear tank to add certain materials. The placement of the materials displaces the air in the tank headspace. Styrene emissions are assumed to occur during the time the drum is being retrofitted with the cover and during the use of the entire drum (specifically toward the end of the drum life when the near empty drum is poured into another drum containing the same color gelcoat). The exposures measured in the gelcoat room are, in fact, the result of agitating, pumping, and handling of the gelcoat. As a result, the mix plant operator wears a respirator during this process. It should be noted that the gelcoat and resin mix room were not well-ventilated.

Noise

All personal and area measurements were below the OSHA Permissible Exposure Level (PEL) of 90 dBA. The gel-coater and gunner exposures are above the NIOSH Recommended Exposure Level (REL) and OSHA Action Level (AL) of 85 dBA. In a number of cases, the standard deviation of the measured noise levels indicates that there was great variation in workers' noise exposures. Certain phases of the job are noisier than others or there may be an impact/impulse component to the noise.

Sound exposure levels in Plant 6 are on average 2-4 dBA higher than the VEC plant 7 levels (an increase of 3 dB is a doubling of the sound energy). Plant 6 sound levels are slightly above the NIOSH REL of 85 dBA.

Recommendations

In summary, the objective of this study was to quantify the noise and styrene exposures occurring in both an open and closed mold plant and to evaluate the presently installed engineering controls to reduce styrene exposures. The effectiveness of the styrene controls examined in this study was evaluated by measuring styrene exposures in personal breathing-zone and general-area samples during typical work shifts. Results suggest that operating under a closed mold system does reduce the amount of styrene vapor in the air to 0.14 ppm in areas upwind of the VEC Cells, to between 3.7 and 12.2 ppm in the actual VEC cell (location of styrene source). Personal exposures of employees working in the VEC cells ranged from a non-detected value to 20.7 ppm. However, it should be noted that styrene concentrations in the resin mix room and gel coat room were not as well controlled. The geometric mean concentrations measured in the resin mix and gel coat room are 8.4 ppm and 12.2 ppm respectively.

Results for the open mold plant suggest that this operation was not as well controlled as the closed molding process. The personal breathing-zone geometric mean exposures measured ranged from 30.3 ppm (gelcoater) to 82.8 ppm (hull roller). The general- area concentrations measured ranged from 2.2 ppm in the northeast region to 28.7 ppm in the southwest region.

The following recommendations are made with the intent to mitigate or eliminate some of the concerns associated with the measured styrene and noise exposures.

Plant 6

As expected, the highest exposure levels were in the open mold plant. The following recommendations should be considered in Plant 6:

- A redesign of the ventilation systems, specifically in the hull area (north center region) and deck production lines (northwest region), should be evaluated and considered. Since part of the ventilation system was modified to accommodate larger boat component production in the hull area, it was not configured properly to capture the styrene-contaminated air from the production areas. In the deck area, a combination of a push/pull ventilation system including the relocation of the exhaust vents (e.g. locating the vents to the sides closer to the source) would eliminate the problem of having all of the styrene-contaminated air flow downstream to the exhaust hood, improving the air quality in the facility. Cross-contamination is occurring because air does not flow directly into the exhaust.
- If the ventilation systems in the deck area is not reconfigured (as suggested above), a barrier should be considered to help with dispersion of contaminated air between the deck lines. The effectiveness of the ventilation system should be re-assessed once the barrier in the deck-line is installed. The minimum cross contamination would occur with a partial barrier or a curtain barrier.
- A company policy should be established to prevent the obstruction of the exhaust hoods in any part of the plant.
- The employee locker room should be re-located away from the deck lines where the highest styrene concentrations were measured.
- Employees should refrain from working downstream of the mold within a line. Preventative measures should be clearly established for rollers since they are the most highly exposed. While this is an established policy, modification to the process steps may need to be considered in order for workers to better follow the guidance.
- Managers' implementing changes should consider the need to keep or reduce some of the workers' noise exposure to levels below 85 dBA. After implementing changes, it may be necessary to re-evaluate noise exposures.

Plant 7

The closed mold system appeared to effectively control the amount of styrene released into the air during molding. This process, however, is not always economically feasible for all styles, quantities, and sizes of boats. However, several areas of concern should be addressed, particularly in the storage areas. The following recommendations are suggested:

- An investigation should be conducted in the resin mix room and gelcoat storage room to identify the source of styrene vapors. Measures should be taken to more effectively control these emissions.
- When possible, the sprayer should spray in the direction of the air flow. Because of the distance from the exhaust hood to the bow of the mold, the current ventilation system is performing more like a dilution system. It may be more effective to provide exhaust ventilation closer to the molds and at higher velocities to contain the styrene-contaminated air.
- Short-term exposures for employees that are gelcoating in the VEC cells should be measured.
- The respiratory protection program should be continued until it can be proven that workers are adequately protected.

Noise

The results of the noise monitoring suggest the need for noise control of certain tasks. At the present levels, the employees of Plant 6 should be enrolled in a continuing, effective hearing conservation program. A description of the phases of an effective hearing conservation program are detailed in the NIOSH criteria document or part (a) of the OSHA noise exposure standard (29 CFR 1910.95).4,

An additional concern is the potential effect on hearing from the interaction between noise and styrene. Ongoing research in Europe indicates that levels of noise that would be safe under clean conditions may interact with styrene to increase the probability of hearing loss in workers. ACGIH, since its 1998 Threshold Limited Values and Biological Exposure Indices (TLVs® and BEIs®) publications, has included a note in its Noise Section advising periodic audiograms in cases of combined exposures to solvents and noise. Since hearing loss is a permanent disability, management is encouraged to consider a policy that is more conservative than the NIOSH noise and styrene criteria for those workers exposed to both agents.

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