WALK-THROUGH SURVEY REPORT: STYRENE AND NOISE EXPOSURES DURING FIBER REINFORCED PLASTIC BOAT MANUFACTURING

at

Sea Ray Boats, Inc.
Vonore, Tennessee

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SITE SURVEYED:	Sea Ray Boats, Inc Vonore, Tennessee
SIC CODE:	3732 (Boat Manufacturing And Repair)
SURVEY DATE:	October 27-28, 2005
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Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

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 1971 by the Occupational Safety and Health (OSH) Act of 1970, 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 October 27-28, 2005, researchers from the Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) conducted a walk-through survey at Sea Ray Boats Inc., in Vonore, Tennessee. The primary purpose of this walk-through was to learn more about the fiberglass-reinforced plastic (FRP) boat manufacturing industry and to assess the suitability of this facility for an in-depth survey. The main goals for the walk-through survey included performing a preliminary assessment of the occupational exposures to styrene vapor in air and observing the effectiveness of engineering exposure-control measures during the FRP boat manufacturing operations. A secondary objective was to perform a preliminary assessment of the noise exposures occurring during these operations.

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. Styrene is a fugitive emission, a result evaporating from resins, gel coats, and putties (gunks) used in the manufacturing process. The thermo-set polyester production resin used at this plant is compliant with the U.S. Environmental Protection Agency (EPA) requirements for Maximum Achievable Control Technology (MACT) and contains approximately thirty-four 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. This 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 a part is formed from the polymer. However, due to the volatility of styrene, vapors from the application and curing process may pose an inhalation exposure hazard for workers near the process.

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 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 Permissible Exposure Limits (PEL);[15] (2) The NIOSH Recommended Exposure Limits (REL);[16] and, (3) the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLV®).[17] 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 vapor in air is 50 ppm for a 10-hour time-weighted average (TWA) (meaning the limit applies to the average exposure during a work day of up to 10 hours and a work week of up to 40 hours), with a 15-minute short-term exposure limit (STEL) of 100 ppm, limiting average exposures over any 15-minute period during the work day.[17] 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.[18] The ceiling limit restricts exposures for any portion of the work day. The American Conference of Governmental Industrial Hygienists (ACGIH) revised its Threshold Limit Value (TLV®) in 1997, and recommends styrene be controlled to 20 ppm for an 8-hour TWA exposure with a 40 ppm, 15-minute short-term exposure limit (STEL).[19]

In February 1996, the Styrene Information and Research Center (SIRC) and three other styrene industry trade associations (American Composites Manufacturers Association, National Marine Manufacturers Association, and the International Cast Polymer Association) entered into a precedent-setting arrangement with OSHA to voluntarily adhere to the 50-ppm level set by the 1989 update of the OSHA PEL (which was later vacated by the courts). The SIRC encouraged its members to continue to comply with the 50-ppm standard as an appropriate exposure level for styrene, regardless of its regulatory status.[20]

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, the concentration of styrene in the workers' breathing zones. Recent developments of robot application of gel coats may also provide protection by reducing process emission of styrene through controlled spraying and reduction of the amount of gelcoat overspray.

General Information

Sea Ray Boats is the largest manufacturer of recreational boats in the United States, producing more than forty models ranging in length from 18 to 68 feet. Four families of Sea Ray boat products include sport boats, sport cruisers, sport yachts, and yachts. In 1986, Sea Ray became a part of Brunswick Corporation making Brunswick Corporation the world's largest producer of marine engines and boats. Brunswick has six Sea Ray Boats manufacturing facilities in the United States: the Knoxville Plant, Riverview Plant, Tellico Plant, Palm Coast Plant, Sykes Creek Plant, and Merritt Island Plant. The Sea Ray Boats' Product Development and Engineering facility is located in Florida. This report will focus solely on the Tellico Plant located in Vonore, Tennessee.

The Tellico Plant produces 18 ½- to 24-foot sport boats. The models currently manufactured at this facility are the 185SP, 195SP, 200 Select, 200 SD, 205 Sport, 220 Select, 220 SD, and 240 SD. This facility produces approximately 37 boats per day (148 per week). The facility size is roughly 274,000 square feet on 48 acres of property. There are approximately 600 hourly employees and 43 salaried employees working at the Tellico Plant.

The majority of the FRP parts produced at the Tellico Plant are manufactured using an open-molding process; however, approximately 50% of the small parts produced are manufactured using the closed-mold process. These parts include hatches, motor boxes, and similar pieces. Thirty percent of hulls by boat count are produced using the closed mold process as well. Currently, the 185SP, 195SP and 200 Sport hulls are manufactured using the closed mold process. The 185SP and 195SP have a hull and liner integrated as one part. For these boat models, two large parts are produced at one time; therefore, the conversion to closed molding is equivalent to producing two large parts (i.e. hull and liner) by the traditional open mold process. The Tellico Plant predicts that by November 2006, 50% of its hull production will be manufactured using closed-mold processes.

Process Description

The Tellico Plant has several innovative state-of-the-art processes that enable Sea Ray boats to manufacture a high volume of boats using minimal manual labor. These processes will be discussed in detail below. The traditional open-molding process will be described first, followed by the closed molding process.

Open Molding

In open molding, fiberglass boat parts are built from the outside in accordance with the process outlined below.

1. The mold is sprayed with a layer of gel coat, which is pigmented polyester resin that hardens and becomes the smooth outside surface of the part.

2. The inside of the hardened gelcoat layer is coated with a "skin coat" of chopped glass fibers and polyester resin.
3. Additional layers of fiberglass cloth or chopped glass fibers saturated with resin are added until the part attains final desired thickness. These layers are compressed by rolling the surface by hand.

Styrene exposures occur at all three steps of the open molding process mentioned above. Both the gelcoat and the polyester resins contain a significant percentage of styrene. The proportions (by weight) of styrene in resins used for the open-molding process are as follows: 34% styrene for skin-coat resin, and 33.9% to 35% styrene for bulk resin. The percent of styrene in exterior gelcoats ranges from 22% to 33.47% depending on the color of the gelcoat and other manufacturing environmental factors.

Gelcoating Liners

A liner is a part that is inserted into the hull to strengthen the structure of the boat. Liners are gelcoated in a gelcoating station (booth) in Building 5. A controlled-spray process is used to decrease the amount of gelcoat overspray thus decreasing the concentration of styrene in the surrounding ambient air. This process is cost effective, easier, and cleaner than the traditional gelcoating process. All gelcoaters are trained in controlled spraying. All liner molds for gelcoating have steel rods (one foot in length) that hold up medium-weight paper surrounding the liner. The paper is securely taped to the surrounding areas of the liner. The gelcoater is not allowed to spray more than halfway up the paper. This is used as a guide for the gelcoater to know how much overspray he/she is producing. All guns (model No. ATG-3500, Magnum-Venns, Kent, Washington) used for gelcoating in this area are calibrated before each shift. All guns used for interior gelcoating have a Fluid-Impingement Technology (FIT) tip which is non-atomizing. No barrier coats are applied to the liners of the boat.

Lamination of Liners

Liners are laminated in Building 5 opposite to the liner gelcoating area. Three liners are arranged in a series per bay and two workers work on each liner at a time. Some employees also apply wood bracing to the liners for ease of assembly. The majority of the fiberglass applied to make the FRP boats is chopped. All open-mold laminators wear half-faced piece respirators (3M-6000 Series) with organic vapor cartridges. Canvas tarpaulins servings as barriers to air movement are strategically placed overhead in areas where small parts and liners are laminated. This enables the styrene-containing air to be directed and exhausted out from the opposite end of the room. Overhead fans are also available for employees' personal preference (mostly used during hot summer days). During cool winter days, the supply air is heated.

Grinding

Most of the grinding, cold-cut processing, or trimming is done in Building 1. A hole-cutting robot is used to accurately cut hulls and decks to specifications with high accuracy. This robot uses parametric shape-cutting programs and touch-sensor alignment to ensure precise work. Each of the grinding booths in this area of Building 1 has a ventilation system designed to collect particulates. Respirators worn in this area are for particulates as well.

Deck Laminating

Decks are laminated in steps due to the amount of fiberglass and resin needed to attain the desired thickness. The heat generated by the curing of the resin hinders the amount of fiberglass and resin that can be applied at one time. In open molding, all fiberglass is applied by using a chopper gun (continuous woven fiberglass strands fed from a spool to the chopper gun which cuts the glass into one-inch pieces). During deck laminating, the resin-to-glass ratio is tracked by using real-time material-monitoring stations that allow workers to monitor the amount of resin and fiberglass used. This system is also used by management to determine how much resin and fiberglass was used in each boat. The optimum resin to glass ratio is between 28 and 32 for the skin coat. The first layer of fiberglass and resin applied to the decks is the skin coat which is a light application of resin. Two ounces of resin per square inch are used in the skin layout. In the bulking station, a second coat of fiberglass and resin is applied to the decks. The optimum resin to glass ratio for bulk is 32 to 36. Four to six ounces per square inch of resin are applied during this step. The finishing station consists of the application of the last layer of fiberglass and resin. In this stage, the final desired thickness is achieved. Two ounces per square inch are applied to the decks in this stage.

Closed Molding

The two types of closed-molding processes used in this plant are a derivative of Resin Transfer Molding (RTM). They are:

- Multiple Insert Tooling (MIT)
- Zero Injection Pressure (ZIP)

Small Parts

Approximately 50% of all small parts at the Tellico Plant are produced by closed-molding processes. The small-parts closed-molding manufacturing line is located in Building 2. A form of Resin Transfer Molding (RTM), more specifically, Multiple Insert Tooling (MIT) is used to fabricate small parts. RTM is a pressure-driven process, whereby resin is injected into a closed-mold cavity at higher-than-atmospheric pressure. The MIT process, a derivative of RTM, involves three layers. A thick previously assembled fiberglass part is inserted into the two part molds. An assembly line is used to efficiently make the small parts. The small-part assembly line proceeds in the following order: gelcoating (in a booth), glass load, injection, and pull. This small-parts assembly line produces 190 parts per day and operates in 10 hour shifts. According to facility management, closed-molding technologies significantly reduce environmental emissions and worker exposure to styrene to a relatively uniform extent when compared to traditional open-molding. The reaction which consumes styrene is completed before molds open thus very little styrene emission occurs.

Large Parts

Robotic Gelcoating

Due to its high percentage of styrene, gelcoating in FRP boat manufacturing emits a considerable amount of styrene into the air. To reduce the styrene emissions into the air, Sea Ray Boats has converted some of its labor intensive hand-sprayed gelcoating to robotic gelcoating. Gelcoat is applied to the hulls and decks by using FANUC P-200 Robotic gelcoaters. The two robots are located inside a gel-coat booth with two sliding overhead doors; the robots are operated from an adjacent control room. The robots ensure consistency of gelcoat finish and thickness. The system is designed to locate the mold surface thru laser alignment, and precisely apply gelcoat over entire hull and deck. The hulls are prepared prior to the gelcoating by two operators. They apply tape to the edges of the boat mold in the gelcoat booth, and boat model from the control room. The actual gelcoating takes approximately ten to twelve minutes. Once the hull is completed, the operator and an assistant remove the tape form the areas surrounding the hull. This is the only time in which the operator could be potentially exposed to a styrene vapors. The amount of time the operator and his assistant spend in the gelcoating booth is approximately 3-4 minutes.

Rimfire Process

The latest state-of-the-art technological automation at Sea Ray is the Robotic Fiberglass Preform Cell. It is a multi-axis server-driven robot that controls the dispersion rate of the continuous woven fiberglass strand on horizontal and vertical surfaces. The robot chops, sprays, and heats fiberglass pieces and applies them to a previously gelcoated mold. This process is done by a robotic laminator that is fed fiberglass strand from a spool, and chops it into small pieces. The glass is then fed through an open flame to make the fiber sticky so it will adhere to the hull. These hulls have an 8-ounce of chopped fiberglass per-square-inch base. This robotic lamination process takes about 10-12 minutes. A special engineered fabric is applied shortly after the chopped glass is sprayed. This engineered fabric aids in meeting the thickness specifications. Once the hull has been sprayed a liner is placed on the bottom of the boat. This is an innovative process that saves time, because the liner does not need to be bolted later.

Injection of Closed Molding

Another type of RTM closed molding used to make hulls and liners is the Zero Injection Pressure (ZIP) closed-molding process. This type of closed molding does not require a preassembled part. It consists of a matched pair of upper and lower mold caps that are clamped together. Once the mold has been prepared as described in the previous paragraph, it is closed and the resin is injected from the top of the mold through small ports distributed throughout the top area. The resin is pumped from a tank adjacent to the closed-molding area. The connecting tubes are overhead and below-atmospheric pressure is created throughout the closed mold to fill the fixed cavities with resin. Thirteen hulls per day are manufactured using the ZIP process. Once a part has been cured, it is pulled from the mold yielding the formed hull and liner. This process can potentially eliminate the styrene emissions contributed by the lamination, rolling, and curing process of open molding. According to Sea Ray representatives, boats built with this system are stronger, safer, and more reliable.

Health and Safety

A Frees ventilation system is installed in Building 1 (lamination and closed-mold small-parts area). A Schoeffner ventilation system is installed in Building 5 (small parts, open molding, and liner area). An additional make-up air system and three additional exhausts were also installed in Building 5. This exhaust/ventilation system was designed by Rogers and Morgan. Half-face piece respirators and face shields are worn by all gelcoaters spraying in spray booths. All open-mold laminators wear half-faced piece respirators (3M-6000 Series) with organic vapor cartridges. Laminating employees rotate throughout the day from gunning (spraying of chopped fiberglass and resin) to rolling (hand saturation of resin with fiberglass). Gloves are provided to each employee, but are not required to be worn. All cleaning stations have an acetone solvent cleaner to clean resin from gloves or other resin covered area. Acetone is used mostly in the laminating areas. All employees or guests entering any building at this facility are required to wear safety glasses.

Hearing Conservation Program

A hearing Conservation program is implemented at this facility. The areas that are tested are: Lamination in Building 1; Assembly, Small parts, and closed molding (RTM) in Building 2; and Woodshop and Upholstery in Building 3. All hearing tests (Audiometric exams) are contracted out.

Measurement Methods and Results

Styrene

Styrene detector tubes (Drager Tube model no. 67 33 141) were used to estimate concentrations of styrene vapor in the air in areas where NIOSH researchers observed a high use of styrene-containing products. The range of detection of the tubes used was 10 to 250 ppm. Results are given in Table 1.

Table 1: Results of Styrene Detector Tube Samples taken throughout the Sea Ray Boats in Vonore, Tenessee		
Building	**Description**	**Concentration**
5	Laminating Station	30-35
5	Gelcoating	30
1	Deck Laminating	25
1	Bulk Laminating	45-50
2	RTM Small Parts	5
1	Finishing Station	40
1	ZIP Process (closed molding)	15-20*
1	Robotic Gelocating	25**
1	Injection Molding (closed molding)	n.d.***
1	Pulling of Mold (closed molding)	3***

***** A open molding operation was nearby when this sample was taken
******The amount of time required to draw the complete styrene detector tube sample exceeds the amount of time the employee is near the styrene emitting source.
*******Represents the ZIP closed molding without cross-contamination from the adjacent open molding operations

Noise Measurements

In addition to measurements of styrene exposure, noise levels were also measured. Noise level measurements were collected using two Larson-Davis 706 Type 2 dosimeters. 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.[21] Dosimeters were set to “SLOW” response and A-weighting frequency filter. The equipment was calibrated by the manufacturer before the study. The dosimeters were calibrated before and after the surveys. Data from the dosimeters were downloaded to a personal computer and analyzed using the Larson-Davis Blaze™ software.

Noise measurement results are illustrated in Figures 1 and 2. These results only indicate noise levels in dB(A) of certain tasks observed during the survey and cannot be used for calculations of time-weighted noise exposure or dose during a work day. The corresponding job tasks are indicated on the each figure.

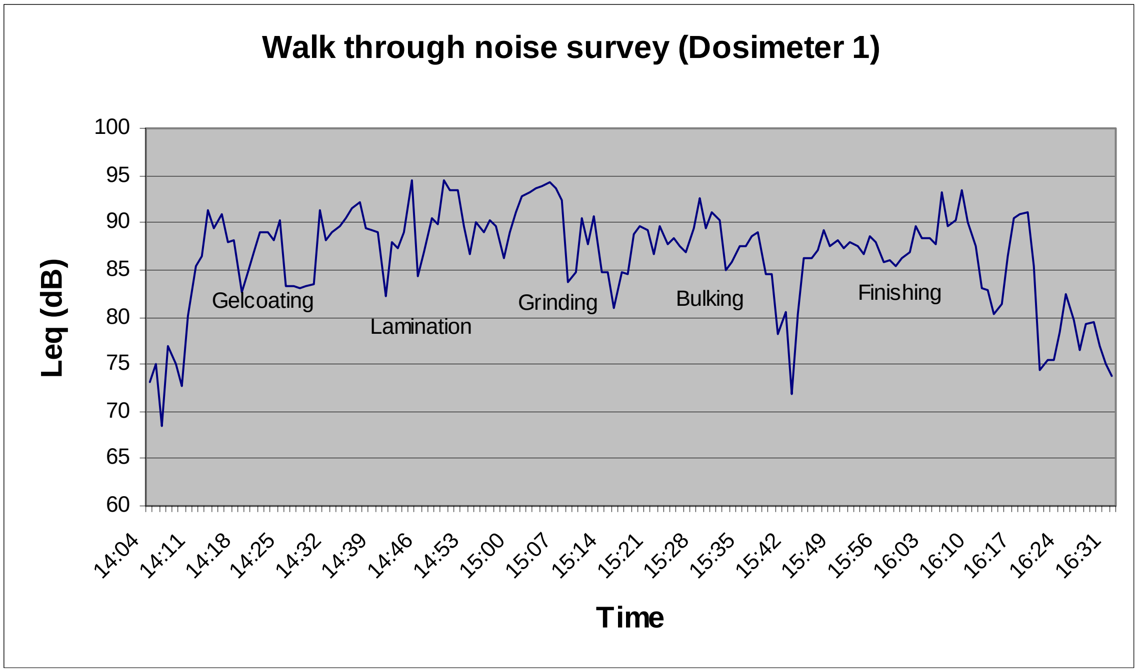

Figure 1: Noise measurement results Dosimeter 1

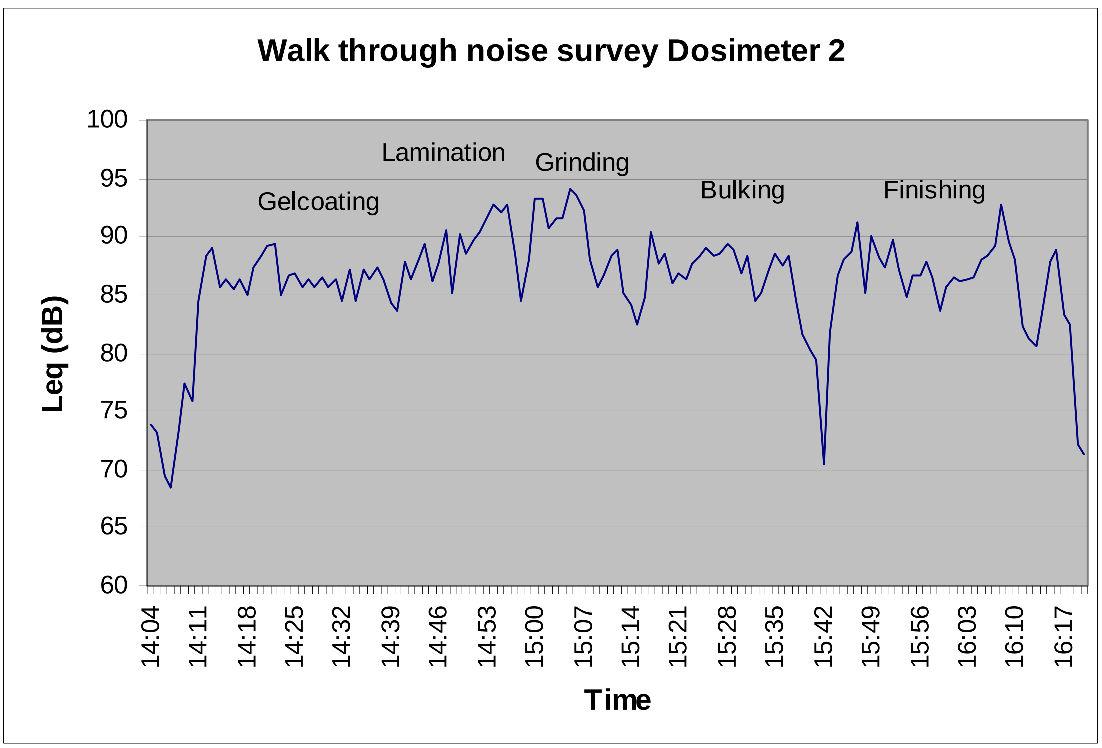

Figure 2: Noise measurement results Dosimeter 2

Preliminary Conclusions and Recommendations

The Tellico Plant has gone to great lengths to automate many steps required to build FRP boats. The robotic forming and finishing processes allows for controlled use of styrene-containing products and lower styrene exposures for employees. The company representatives believe that cross-contamination from open molding to closed molding can exist due to the proximity of the two manufacturing lines. Adjacent to the ZIP closed-molding production line is an open-molding lamination line. NIOSH researchers collected three styrene detector-tube samples (robotic gelcoating, injection molding, and pulling of mold) on a different day in order to avoid cross contamination. An in-depth survey is recommended for this plant.

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