BASELINE CHARACTERIZATION OF EMISSIONS
FROM FIBERGLASS BOAT MANUFACTURING
FOR
NATIONAL MARINE MANUFACTURERS ASSOCIATION

NMMA

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August 1997

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1.0 INTRODUCTION

Under contract to the National Marine Manufacturers Association (NMMA), Stelling Engineering, Air-Tech Environmental, and Radian International conducted testing in April 1997 to characterize baseline emissions from gelcoating and lamination of fiberglass boats. Testing was conducted in accordance with the *Quality Assurance Project Plan for the National Marine Manufacturers Association Baseline Emissions Testing Project* (QAPP) approved by the U.S. Environmental Protection Agency (EPA) in March 1997. A quality assurance (QA) audit was performed by the EPA during this program. Visits by state regulatory authorities and other interested parties were also made during testing.

The test program was designed to be as representative as possible of actual fiberglass boat manufacturing. Testing was conducted at the U.S. Marine (Bayliner) fiberglass boat manufacturing, research, and development facility in Arlington, Washington, in an enclosure (inside a wooden model fabrication area) made available for this purpose. The volatile organic compounds (VOC) measured during this program were generated from operations identical to those in actual production, that is, using actual boat part molds, spray equipment, resins and gelcoat, and laminating procedures and techniques typical of the industry. Experienced manufacturing personnel conducted the lamination and gelcoating. Only a few runs incorporated a mold or spray techniques not typical of the industry; such runs were designed to produce data for comparison with previous emission tests.

During this sampling program, Research Triangle Institute (RTI) conducted a research program to ascertain the viability of measuring emissions

from lamination and gelcoating operations using a mass balance approach. RTI's program was funded by the EPA's Office of Research and Development (ORD) and will be reported independently.

1.1 **Background**

Within the past two years, several important sampling and analysis programs have sought to determine styrene emissions from open molding of polyester resin fabricated parts. Most important among these studies were the studies conducted by RTI for the EPA and by Dow Chemical USA for the Composite Fabricators Association (CFA). The results from these programs raise questions about the emission factors published in the EPA's compendium of emission factors, AP-42, especially for molding of large parts manufactured by the marine industry.

Still, none of the tests to date adequately represent industry practice or conclusively demonstrate the effect of mold size and styrene content of resin on emissions. For example, the results of this test program indicate that the relationship between emissions of styrene as percent of available styrene in the resin and increasing styrene content does not appear to be constant. Further, an increase in mold size resulted in increased flux emissions (pounds styrene per square foot of surface area of mold) but decreased normalized emissions (pounds styrene per 1000 lb resin per square foot of mold surface area). Also, none of the previous tests included gelcoat containing methyl methacrylate (MMA), which is common in the boat building industry.

1.2   <u>Purpose of Testing</u>

The primary project objective was to characterize total hydrocarbon (THC), styrene, and MMA emissions from the open molding process that is representative of fiberglass boat manufacturing, specifically spray up gelcoat application and resin application. Hand lay-up, defined as the application of glass and resin that are mixed manually and applied by brush, was not part of this study. A technique comparable to hand lay-up found in the industry is the use of a flow chopper, a glass chopper similar to the resin chopper gun but equipped with a low-pressure, non-atomized resin delivery system resembling a nozzle not unlike a shower head that exudes catalyzed resin. The principal difference between this technique and conventional spray up application is that resin atomization is avoided. Sampling during lamination using a flow chopper was conducted to augment the test matrix planned for this program; this supplemental sampling was funded by the EPA through RTI.

This study was designed to produce data for estimating emissions from lamination and gelcoating in fiberglass boat manufacturing plants. The data and analyses reported in this document are intended to be useful to plants in compiling emission inventories and assessing permit needs or changes.

1.3   <u>Testing</u>

Sampling was completed by Darrell Doerle of Air-Tech Environmental and John Stelling of Stelling Engineering. Testing was coordinated with U.S. Marine personnel by John McKnight, NMMA's project manager. Larry Dargitz of U.S. Marine operated the resin application

equipment, and Ken Warren of U.S. Marine applied gelcoat for those experiments.

Tests were also coordinated with Bob Wright, Emery Kong, and Mark Bahner of RTI. RTI conducted a study in an adjacent enclosure under contract to the EPA's ORD to measure emissions from the same lamination operations as conducted for this program but applied to a small panel. The goal of their program was to develop a simplified material balance approach for determining emissions from fiberglass lamination.

1.3.1   Test Enclosure

The testing was carried out at the U.S. Marine manufacturing and research facility in Arlington, Washington. The test area was located in a wooden model fabrication area where tool plugs are fabricated. A large test enclosure (20 ft by 45 ft by 14 ft) meeting the total temporary enclosure (TTE) requirements of EPA Method 204 (included in Appendix A) was erected in this 27-ft by 50-ft area to accommodate tools (i.e., molds) ranging from 18 to 28 ft in length. Sufficient space was provided in the enclosure to allow technicians to work around the tool and to move the tool as needed to apply gelcoat and resin. A description of the TTE is contained in Appendix B. Natural draft openings (NDOs) were arranged in accordance with EPA Method 204**.** Measurements were made to ensure that the air velocity across the mold surface was comparable to that measured in the manufacturing area.

The exhaust system for the entire model preparation room comprised a dual pick-up system at one end of the room (near the constructed enclosures) exhausting to a single induced draft fan. The fan had 20,000-cfm

capacity, far more than needed to exhaust the two enclosures. At the start of the program, some of the pick-ups were closed to develop sufficient draw through the enclosures. The flow rate was balanced with both enclosures in use so that the turnover through the large enclosure used for NMMA testing was comparable to that in the manufacturing areas on site (i.e., about 16 room changes per hour). On-site checks in the production area verified this range.

The enclosure was equipped with two 10-in. plena for exhausting the enclosure. Three-inch openings were installed every 3 ft in each plenum and covered with spun fiberglass filter media. Air was supplied to the enclosure through a 12-in. plenum in the ceiling of the enclosure. This plenum was open on both ends, limiting the NDO associated with the inlet air plenum to 1.571 ft^2. The enclosure was equipped with a door (which remained closed during testing) and a zippered end for changing application equipment and molds between tests. Thus, the openings on both ends of the inlet air plenum were the only NDOs. The openings in this plenum satisfied the requirements of Method 204 for a TTE, representing only 0.043 percent of the total surface area of the enclosure. Also, considering a flow rate of 2,600 to 3,300 cfm, the velocity at the NDO was at least 1,655 ft/min, also satisfying Method 204 requirements. Air coming into the enclosure was monitored continuously for hydrocarbon concentration during each test run in accordance with Method 204; these data were recorded with other continuous monitoring data.

1.3.2 Process

The polyester resin spray-up application process commonly used in the boat building industry uses a "chopper gun" to apply a laminate. The chopper gun dispenses polyester resin, catalyst, and chopped glass fibers.

Continuous strand fiberglass roving is fed to a chopper unit mounted on the spray gun and is cut into chopped fiber lengths of approximately 1.5 in. long. The chopped fiber is ejected from the chopper unit and is captured by the resin fan pattern a short distance from the spray gun. The mixture of the catalyzed resin and chopped fiber is deposited on the mold by the spraying action. Typical of fiberglass boat manufacture, woven roving (a fabric material) was used with resin application by spray gun and flow chopper for the addition of this reinforcement. A Venus Gusmer GO3 low-pressure slave arm internal mix airless chopper gun equipped with a 5003 tip, typical of guns used in the industry, was used for spray application of resin and chopped glass during this program.

Resin was supplied to the chopper gun and the flow chopper by a Venus Gusmer system at a pump ratio of 11 to 1. The methyl ethyl ketone peroxide (MEKP)/dimethyl phthalate (DMP) catalyst was internally mixed for both chopper gun and flow chopper, with the catalyst delivered by a slave pump system. The flow chopper was also a Venus Gusmer design. The resin is delivered at a much lower pressure and no air is used to dispense the resin into the chopped glass. The glass is chopped into lengths using the same method as in the chopper gun, but because there is no atomizing air, the dispersion pattern of glass and resin mixture is more narrow.

Gelcoat is applied in the boat building industry using a spray gun, typically an airless air-assisted spray gun. For this program, gelcoat was delivered to the spray gun using a Poly-Craft pump system at a pump ratio of 23 to 1. Catalyst, delivered using a metered feed pump, was mixed externally. A Poly-Craft 755 airless air-assisted spray gun (equipped with a 0.026 tip size) was used during this program.

Spray application was conducted using techniques common to the industry. This study was not intended to compare spray techniques. Therefore, skilled technicians from a manufacturing line operated the gelcoat and chopper guns in all tests, except those included to produce data that could be more directly compared to previous tests.

1.3.3   Sampling Methods and Parameters

Method 25A, continuous monitoring of THC, was used as the primary technique to measure emissions. From the Method 25A results, emissions were calculated using the measured THC concentration as propane, the molecular weight of propane, and the exhaust gas flow rate measured in accordance with Method 2. These results are presented in terms of THC emissions (as propane) for lamination or gelcoating.

Speciation of styrene and MMA emissions (needed during gelcoating) was effected through Method 18 analysis using a gas chromatograph (GC) with flame ionization detector (FID). Method 18 analysis was conducted concurrent with the Method 25A monitoring. The Method 18 results were used primarily to establish the ratio of styrene emissions to MMA emissions during gelcoating. This ratio allowed partitioning of the THC emission rate (as propane) into styrene and MMA components. The Method 18 results were also used as a check on the Method 25A results.

Other measurements made during this program included those variables determined from other studies to have more significant influence on emissions (Table 1-1).

1.3.4   Molds

Four molds were used in this program, three of which are boat part molds in actual use by U.S Marine. Two hull molds represented the typical size hulls common to the industry: an 18-ft runabout and a larger 28-ft cruiser. An 18-ft deck mold for a bow rider model was used to represent a more convex-shaped mold. The mold used during Phase I testing by the CFA was included in this program to provide data for comparison with the results of that previous study. Surface areas of these molds (Table 1-2), determined from engineering drawings and in previous studies, were used to calculate flux and normalized emissions.

Table 1-1
Parameters Studied

Parameter	Test Variable	Measured/Fixed
Resin application method	Yes (2)	Fixed
Tool shape	Yes (2)	Fixed
Resin styrene content	Yes (2)	Measured (vendor)
Tool size	Yes (2)	Fixed
Gel time	No	Measured
Applied thickness	No	Measured
Resin density[a]	No	Measured (vendor)
Resin percent non-volatile[a]	No	Measured (vendor)
Resin viscosity[a]	No	Measured (vendor)
Resin peak exotherm[a]	No	Measured (vendor)
Resin thixotropic index[a]	No	Measured (vendor)
Resin flow rate[a]	No	Measured
Air flow rate	No	Measured

[a]These parameters apply to resin and gelcoat.

Table 1-2
Surface Area of Molds Used in Test Program

Mold	Surface Area (ft²)
18-ft Deck	171.09
18-ft Hull	220.5
28-ft Hull	454
CFA Phase I Mold (controlled spray)	28.06
CFA Phase I Mold (uncontrolled spray)	37.28[a]

[a]Uncontrolled spray of this mold inevitably coated flange extensions, effectively increasing the surface area of the final laminate structure.

1.3.5   Materials

Materials chosen for this program are typical of those used in fiberglass boat manufacturing (Table 1-3). Two styrene polyester resins were used, one with a nominal 35 percent styrene by weight content and the other with a nominal 42 percent styrene by weight content. The gelcoat was a white on white gelcoat containing nominally 32 percent styrene and 5 percent MMA. The formulations used are considered most representative of the range of resin styrene and gelcoat contents in the industry. Based on a survey of industry representatives, the marine industry uses gelcoat that contains MMA as an inhibitor to degradation by exposure to ultraviolet (UV) light. MEKP in a DMP base is the most common catalyst used in the industry for both gelcoat and resin; MEKP/DMP was used in this program.

Table 1-3
Properties of Gelcoat and Resin Materials

	Gelcoat	**Resin 1**		**Resin 2**	
Product number	954WP53	80.654-NMMA		80.604-NMMA	
Manufacturer	Cook Composites and Polymers Co.	Alpha/Owens Corning		Alpha/Owens Corning	
Styrene content, %	32	35.1		42.2	
MMA content, %	5	0		0	
Specific gravity	1.32	1.082		1.09	
Thixotropic index	5.5	4.9		5.71	
Viscosity, cps		RVF #2@ 20 rpm-700		RVF #2@ 20 rpm-700	
	LVF #4@ 6 rpm-14500	RVF #2@ 2 rpm-3400		RVF #2@ 2 rpm-4000	
MEKP catalyst ratio	2%	1.5%	2%	1.5%	2%
Gel time, min	16.5	23.22	17.98	23.48	18.70

1.3.6 Schedule

Testing was conducted from April 2 to April 19, 1997. Set up at the site began March 30, continuing to April 1 (Table 1-4). One to three runs were made each day. Sampling was coordinated with the U.S. Marine personnel supporting the lamination and gelcoating operations and with RTI personnel conducting sampling in an adjacent Method 204 enclosure.

1.4 Organization of the Report

The complete report including all appendices and separately bound field data contains all data from the testing program. The text of the report is intended to stand alone to provide the essence of the results from the sampling and analysis program. This introduction (Section 1) provides a brief

Table 1-4
Test Schedule

Date	Test	Description	Run
2-Apr	NMMA-6-P	18-ft Deck Gelcoat	0402-01
3-Apr	NMMA-8-1	28-ft Hull Gelcoat	0403-01
3-Apr	NMMA-4-1	18-ft Deck 35 % Styrene Resin	0403-02
4-Apr	NMMA-7-1	28-ft Hull 35 % Styrene Resin	0404-01
4-Apr	NMMA-3-1	18-ft Hull Gelcoat	0404-02
5-Apr	NMMA-8-2	28-ft Hull Gelcoat	0405-01
5-Apr	NMMA-1-1	18-ft Hull 35 % Styrene Resin	0405-02
7-Apr	NMMA-7-2	28-ft Hull 35 % Styrene Resin	0407-01
8-Apr	NMMA-6-1	18-ft Deck Gelcoat	0408-01
8-Apr	NMMA-3-2	18-ft Hull Gelcoat	0408-02
8-Apr	NMMA-4-2	18-ft Deck 35 % Styrene Resin	0408-03
9-Apr	NMMA-1-2	18-ft Hull 35 % Styrene Resin	0409-01
9-Apr	NMMA-11-1G	CFA Mold Gelcoat	0409-02
9-Apr	NMMA-11-1	CFA Mold 35 % Styrene Resin	0409-03
10-Apr	NMMA-14-1	18-ft Deck 35 % Styrene Resin - Flow Chopper	0410-01
10-Apr	NMMA-13-1	18-ft Hull 35 % Styrene Resin - Flow Chopper	0410-02
10-Apr	NMMA-11-2	CFA Mold 35 % Styrene Resin	0410-03
11-Apr	NMMA-6-2	18-ft Deck Gelcoat	0411-01
11-Apr	NMMA-14-2	18-ft Deck 35 % Styrene Resin - Flow Chopper	0411-02
11-Apr	NMMA-13-2	18-ft Hull 35 % Styrene Resin - Flow Chopper	0411-03
12-Apr	NMMA-11-3	CFA Mold 35 % Styrene Resin	0412-01
12-Apr	NMMA-5-1	18-ft Deck 42 % Styrene Resin	0412-02
12-Apr	NMMA-2-1	18-ft Hull 42 % Styrene Resin	0412-03
14-Apr	NMMA-5-2	18-ft Deck 42 % Styrene Resin	0414-01
14-Apr	NMMA-2-2	18-ft Hull 42 % Styrene Resin	0414-02
15-Apr	NMMA-16-1	18-ft Deck 42 % Styrene Resin-Flow Chopper	0415-01
15-Apr	NMMA-15-1	18-ft Hull 42 % Styrene Resin-Flow Chopper	0415-02
16-Apr	NMMA-16-2	18-ft Deck 42 % Styrene Resin-Flow Chopper	0416-01
16-Apr	NMMA-15-2	18-ft Hull 42 % Styrene Resin-Flow Chopper	0416-02
17-Apr	NMMA-12-1	CFA Mold 42 % Styrene Resin	0417-01
18-Apr	NMMA-9-1	28-ft Hull 42 % Styrene Resin	0418-01
18-Apr	NMMA-12-2	CFA Mold 42 % Styrene Resin	0418-02
19-Apr	NMMA-9-2	28-ft Hull 42 % Styrene Resin	0419-01

introduction to the purpose of the testing and the schedule for completing the on-site activities. The results of the sampling program are presented in Section 2. Results are presented in tabular format and graphically to simplify review. Section 3 describes the methods used in the sampling program, including those used to quantify parameters not varied during the program, such as gel time and styrene content. Quality control (QC) measures and QA data are presented in Section 4.

Data and material supporting the test report are contained in the appendices, as follows:

- Reference Methods
- Construction of a Temporary Total Enclosure for Volatile Organic Compound Emission Assessment During Manufacture of Fiberglass Boats
- Calculations
- Procedure for and Results of Gel Time Determination
- Material Safety Data Sheets
- Certifications for Gas Standards and Equipment Calibrations
- Bag Standards
- Location and Results of Air Flow over the Mold Measurements
- Comparison of NMMA Results with Those from Other Studies

Copies of all raw data generated by the GC and the THC analyzer, organized by day, and including pertinent process data (spray gun calibrations), have been bound separately for archive at NMMA offices.

2.0   RESULTS

The results of emission testing at the U.S. Marine site in Arlington, Washington, are presented in this section with comparison of the data between tests and with the results of the CFA Phase I studies; further comparison of these results with other studies is appended. The results are presented in terms of emissions as a percent of available compound (i.e., styrene, MMA, and total volatiles), as emissions per unit area of mold surface, and as normalized emissions, that is, emissions per unit mass of resin per unit area of mold surface. All calculations done for these analyses are appended (Appendix C), including a sample calculation showing the complete analysis of data from test runs.

Results demonstrate that the enclosure constructed at the site provided good capture of emissions from the molding process and that all emissions were accounted for in the sampling. The styrene evaporation tests demonstrated that the emission monitoring system provided a good measure of the actual losses. Testing of emissions from lamination of the box mold from the Phase I CFA studies demonstrated that the techniques used in the two studies (i.e., CFA's study and the portion of this study designed to reproduce some of the testing done in the CFA study) were comparable. Results of duplicate testing for each test case provided good closure, within the acceptance criteria specified in the QAPP. In accordance with the plans outlined in the QAPP, all tests of boat mold use were completed with only two runs. A third run was done for one of the test conditions to incorporate the CFA study mold.

2.1   <u>Summary of Results</u>

Table 2-1 presents the average values from the sixteen emission tests conducted at U.S. Marine's Arlington, Washington, site. Three of the tests

were conducted using the same box mold used by CFA/Dow during their Phase I studies (to provide data for comparison with those studies); all other tests were conducted using boat molds and procedures typical of U.S. Marine's boat manufacturing processes. The results of this study are taken as representative of industry practice.

The amount of resin used per part during these studies was much greater than the amounts used in previous studies (Table 2-1). This relative scale of material use and measurement contributed to the consistency of results.

Table 2-1
Summary of Test Results

| Description[a] | Resin Use (lb) | Emissions as Percent of Available | | | Emission Flux (lb/SF) | Normalized Emissions (lb/1000 lb/SF) |
		Styrene	MMA	Volatiles		
CFA Gel	3.2	41.1%	84.0%	46.9%	0.0203	6.36
18 Deck Gel	20.0	42.3%	75.6%	46.9%	0.0228	1.14
18 Hull Gel	25.7	46.4%	73.2%	50.0%	0.0261	1.03
28 Hull Gel	65.7	50.4%	78.6%	54.3%	0.0389	0.59
CFA 35R	8.1	41.8%		41.8%	0.0345	4.89
18 Deck 35R	124.6	12.9%		12.9%	0.0130	0.11
18 Hull 35R	144.5	14.8%		14.8%	0.0143	0.10
28 Hull 35 R	354.4	17.3%		17.3%	0.0234	0.07
18 Deck 35R - FC[b]	114.7	11.9%		11.9%	0.0092	0.08
18 Hull 35R - FC	141.7	10.8%		10.8%	0.0072	0.05
CFA 42R	5.1	48.7%		48.7%	0.0324	6.28
18 Deck 42R	111.8	21.1%		21.1%	0.0284	0.25
18 Hull 42R	142.9	20.7%		20.7%	0.0272	0.19
28 Hull 42R	304.2	23.3%		23.3%	0.0357	0.12
18 Deck 42R-FC	122.2	13.4%		13.4%	0.0125	0.10
18 Hull 42R-FC	154.9	11.4%		11.4%	0.0089	0.06

[a]See Table 1-4 for full description.
[b]Application using flow chopper.

The THC measurements made during this program serve as the principal basis for estimating emissions. Figure 2-1 presents summary

Figure 2-1
Summary Concentration Traces for Boat Lamination and Gelcoating

2-1[a] - Spray v. Flow Chopper: 18 Hull and Deck - 35% Styrene Resin

2-1[b] - Spray v. Flow Chopper: 18 Hull and Deck - 42% Styrene Resin

2-1[c] - Spray: 28 Hull - Both Resins

2-1[d] - Gelcoating
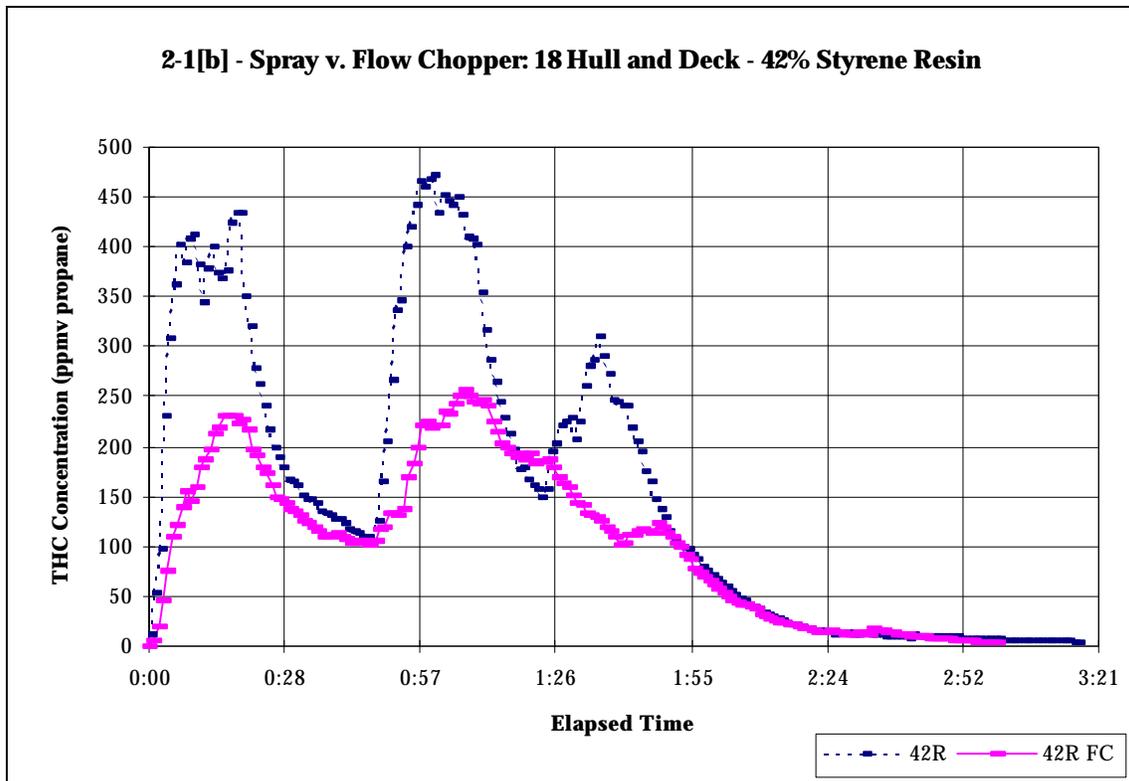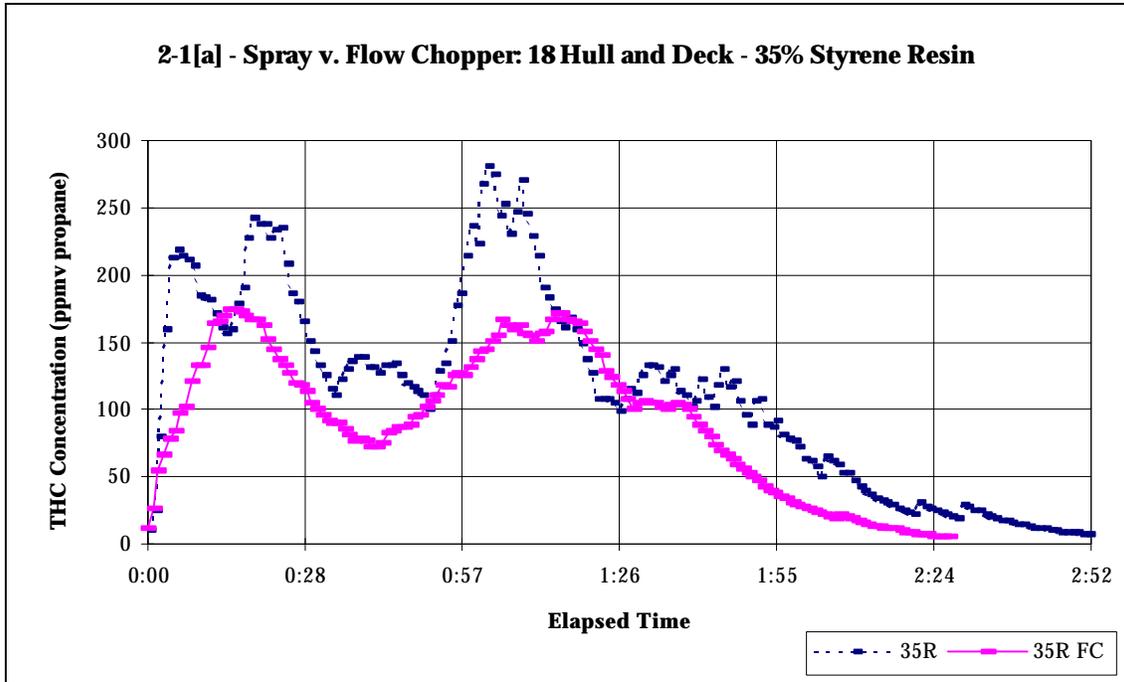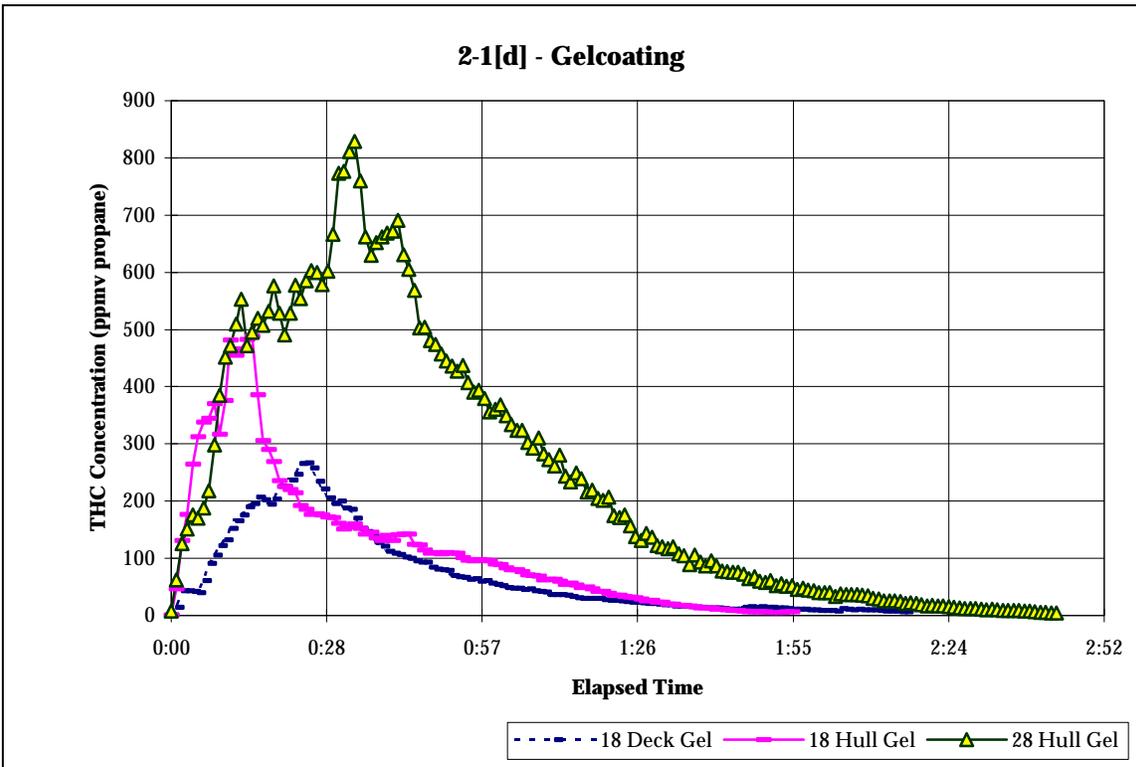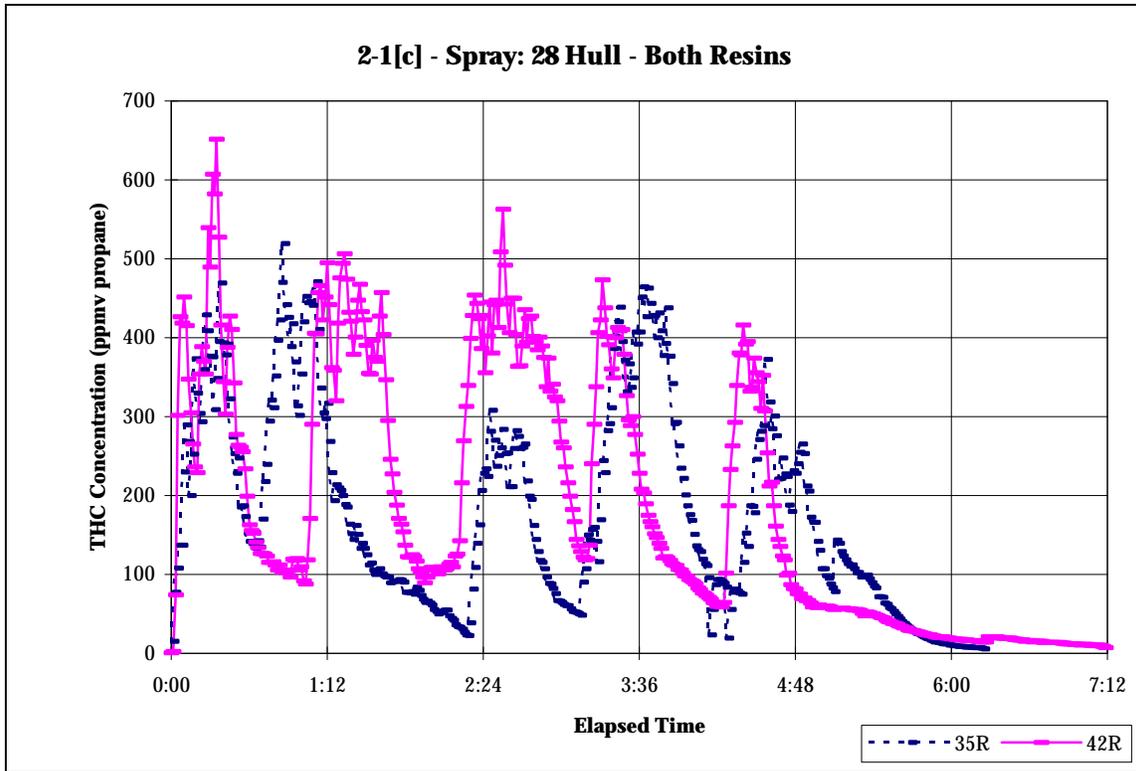
concentration profiles for the testing conducted during the April 1997 deployment. Each of the four frames presents THC concentration traces derived by averaging data from the individual test runs. This figure illustrates some of the differences in the data summarized in Table 2-1.

For example, the data from sampling the exhaust during lamination of the 18-ft mold illustrates the differences between spray up application and application by flow chopper, as well as the increased THC concentrations in the exhaust noted when laminating with a higher styrene content resin (42.2 percent styrene). The data from the 28-ft mold lamination test show that, although the peak concentrations using the two resins were essentially the same, the concentration trace for the 42 percent styrene resin has broader peaks, corresponding to greater mass emission rates.

The summary illustration of the gelcoat data shows the effect of geometry on the concentrations measured. The greater THC concentrations in the exhaust noted during lamination of the 28-ft mold are likely the result of the broader strokes used in gelcoating the part and the distance between the operator and the part during gelcoating. The atomized gelcoat remains airborne for a longer period of time, resulting in greater volatilization and emissions of VOC. The operator can stand closer to the 18-ft hull and make shorter strokes to apply the gelcoat. Also, the operator can coat half of the 18-ft mold surface in a single pass, rather than the minimum two passes required to coat the 28-ft hull mold; this difference is noted in the differences in peak widths. Finally, the 18-ft deck mold is relatively flat, with complex geometry requiring the operator to work close to the mold surface and coat some portions of the mold by brush, reducing the amount of gelcoat atomized.

The results presented in the tables and figures in this report reflect the exclusion from testing of emissions in the long, low-concentration "tail" in each THC trace for each run. This phenomenon has been noted in previous studies and was highlighted in the QAPP as a concern for completing this testing in a timely fashion. Section 2.2 presents the results from some of the early test runs that illustrate that elimination of the "tail" has little if any effect on the results reported herein.

All the data related to emissions from boat gelcoating and lamination derived from this NMMA testing program are summarized in Figure 2-2. This figure presents the results for all tests in terms of emissions as a percent of available monomer. As the results clearly indicate, emissions from gelcoating differ from those associated with resin lamination. Sections 2.4 and 2.5 contain more detailed presentations of the results from gelcoating and resin lamination emission testing.

2.2 <u>Evaluation of Emissions from Continuing Trace Concentrations</u>

The QAPP included the evaluation of a cutoff concentration in the exhaust stream that would allow cessation of sampling before the concentration of THC in the enclosure exhaust reached the background concentration, provided at least 95 percent of total emissions were characterized before cessation of sampling. The first test runs were used for this assessment. The assessment determined that 95 percent of total emissions from lamination and gelcoat operations would be characterized by the time the exhaust concentration reached 75 ppmv as propane. Ceasing sampling at this concentration would reduce run sampling by about 1 hour per run, allowing more sampling runs per day.

Figure 2-2
Emissions as Percentage of Available Monomer

Emissions as Percent of Available Monomer for Boat Tests
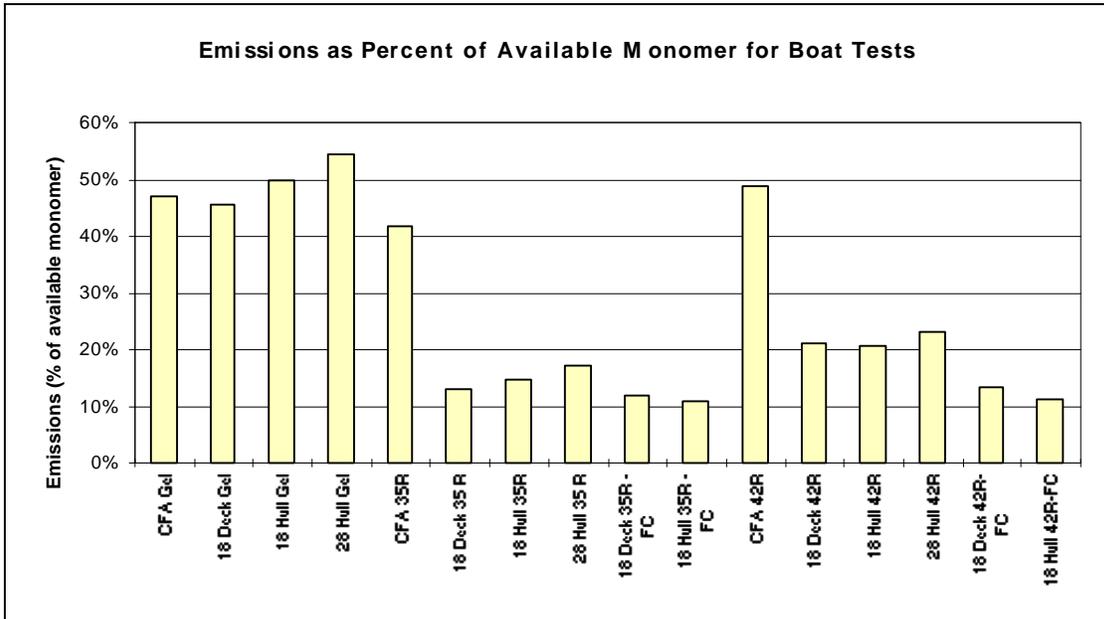
As it turned out, it was practical to continue the test runs until concentrations measured about 7 ppmv as propane. Because the background concentration was about 2-4 ppmv, the difference in concentration was about 4 ppmv, relating to less than 2 ppmv as styrene and representing only 0.2 percent of emissions.

The assessment of the concentration trace for NMMA-4-1 (lamination of an 18-ft deck with 35 percent styrene resin) illustrates this analysis. The concentration trace for run NMMA-4-1 (Figure 2-3) shows the typical pattern of concentration peaks and valleys as resin is applied systematically to the sides of the mold. Resin and glass are applied to the first side, and the mixture is rolled out to remove air bubbles. After the initial coat on this half of the mold begins to gel, the mold is rotated and the first coat is applied to the second side. After the coat on the second side begins to gel, the mold is rotated again and the second layer of glass and resin is applied to the

first side, with some of the glass being woven roving. This process continues until the specified thickness is achieved. As part of the manufacturing procedure, each layer of glass and resin are rolled out. After the final coat of resin is applied and the peak exotherm of the polymerization reaction is achieved, the concentration of styrene in the exhaust stream begins to decrease. All the glass and resin were applied to this mold in about 1 hour. The styrene concentration in the exhaust stream decreased to near background levels in about 1 hour after that point.

Figure 2-3
Total Hydrocarbon Concentration Trace for NMMA-4-1
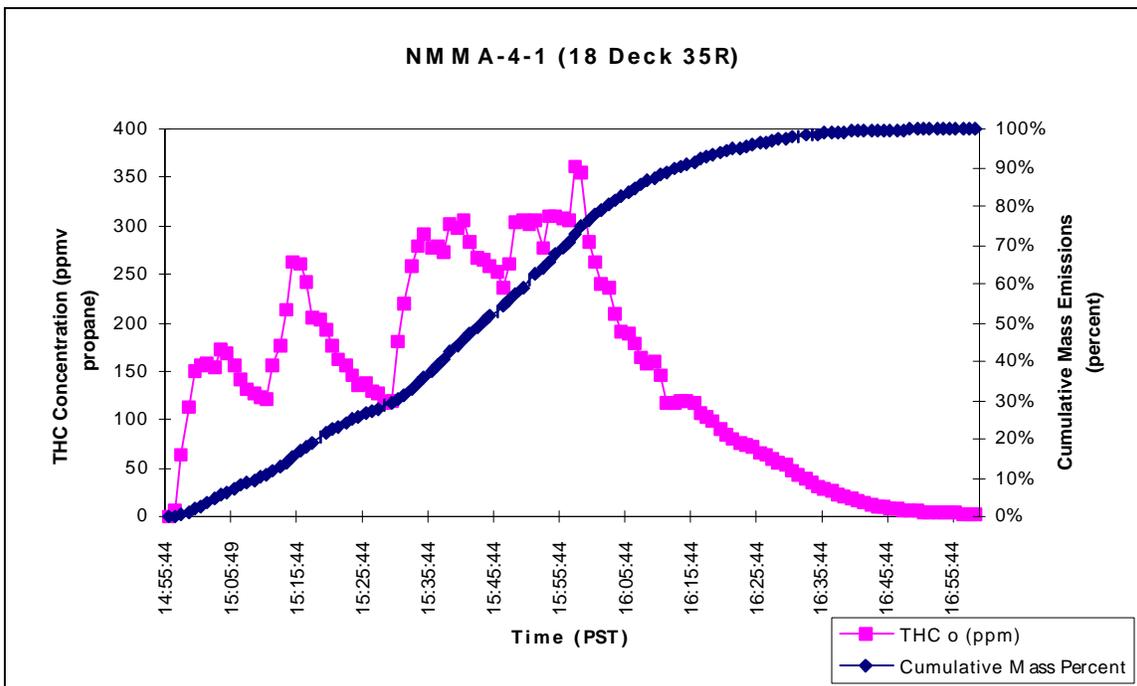
Because the THC associated with the latter part of the concentration trace (from 7 to 4 ppmv) represents about 0.2 percent of emissions, the emissions associated with sampling completely to background levels from the cutoff concentration were less than 0.015 lb. Even this amount represents a worst case assessment (i.e., greatest emissions in the tail) because it assumes that

emissions from all tests are the same, whereas the total emissions from laminating the 18-ft deck mold were less than the emissions from laminating either other part evaluated. The 0.015-lb total would represent a larger portion of emissions for smaller parts, however, such as those included in the previous CFA/Dow and EPA/RTI studies.

Another approach to assessing an appropriate cutoff concentration is depicted in Figure 2-4, a plot of outlet concentration and cumulative emissions. This figure, developed from the same NMMA-4-1 test run, shows that 95 percent of total emissions from lamination were quantified when the exhaust concentration decreased to about 75 ppmv as propane.

Figure 2-4
Concentration v. Cumulative Mass Emissions (NMMA-4-1)
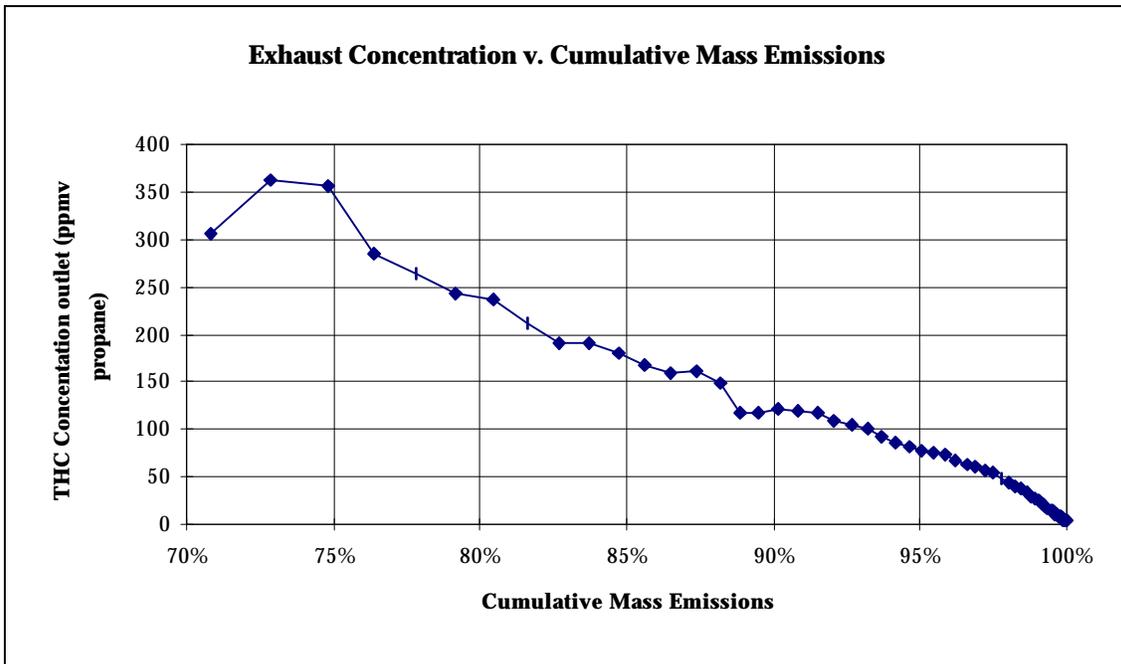
2.3   CFA Mold Results

Part of the test matrix for this program included lamination of the mold used in the CFA Phase I study so that results of both studies could be compared. Testing was conducted using the 35 percent styrene and 42 percent styrene resins, nearly identical to the styrene contents in the resins used in the CFA Phase I study. The initial test run using 35 percent resin (NMMA-11-1R) was conducted using the techniques employed by experienced laminators during actual boat manufacturing. This approach resulted in lower emissions than those measured during the CFA study. To allow comparison to the CFA study, subsequent tests were conducted using methods that resulted in "uncontrolled" spray, including one run during lamination by a completely inexperienced operator (NMMA-11-2R), as evinced by the 10.1 lb of resin used. Although not included among the planned tests, one gelcoat run (NMMA-11-1G) was also conducted by an experienced operator using good technique.

The results of testing during coating of the CFA mold (Table 2-2 and Figure 2-5) indicate an average loss of 38.0 percent of available styrene during lamination using 35 percent styrene resin (not using Run 11-1R in the average) and 48.7 percent of available styrene loss during lamination using 42 percent styrene resin. The results show a higher degree of variability than the results for lamination on the boat molds, largely as a result of the high degree of variability in application technique for inexperienced operators and the influence of the resin weight measurement. The resin extraction equipment disproportionately affected the measurement of small quantities of resin use (Section 3.2.4). Although the results of the various test runs met acceptance criteria, they were not as consistent as the results of emission testing during use of boat molds. Emissions measured during CFA mold lamination in this study were about twice those of comparable tests from the CFA study.

Table 2-2
Emissions Measured During Application of Resin to CFA Mold

Run	Material	Content	Resin (lb)	Percent of Available	Flux (lb/ft²)	Normalized (lb/1000lb/ft²)
11-1G	Gelcoat	37.0	3.2	46.9	0.0203	6.36
11-1R-Ctrl	Resin	35.1	3.5	30.6	0.0114	3.25
11-2R-Unc	Resin	35.1	10.1	29.9	0.0233	2.31
11-3R-Unc	Resin	35.1	6.1	53.6	0.0456	7.48
12-1R-Unc	Resin	42.2	5.4	55.7	0.0441	8.16
12-2R-Unc	Resin	42.2	4.73	41.7	0.0208	4.39

Styrene losses were also considered in terms of emissions per unit area and normalized emissions. Average losses per unit mold surface area (flux) were 0.0268 lb/ft² and 0.0325 lb/ft² for the 35 and 42 percent styrene resins, respectively. Normalized losses averaged 4.35 lb/1000 lb/ft² for the 35 percent styrene lamination and 6.28 lb/1000 lb/ft² for the 42 percent styrene resin. Like the results in terms of percent of available styrene, these results indicate greater losses from use of greater styrene content resins than would be proportional to the actual styrene content. The flux losses show a different trend, but comparison of the emissions in this format is inconclusive because of the only slight difference in averages and the difficulty in consistent resin weight measurement.

In this test series of the program (i.e., using the CFA mold), emission measurements were not always comparable to the amount of resin used, i.e., the emissions as percent of available monomer was not always consistent. The equipment was set up to measure large quantities of resin and gelcoat continuously. The expected quantities were between 100 and 300 lb resin for each test run. The scale selected, therefore, had an accuracy of 0.5 lb, which was satisfactory for the boat lamination and gelcoating tests, but which did not

Figure 2-5

Emissions from Lamination and Gelcoating of the CFA Mold

CFA Mold - Emissions (% Available)

CFA Mold - Emissions (lb/ SF)

CFA Mold - Emissions (lb/ 1000 lb Resin/ SF)
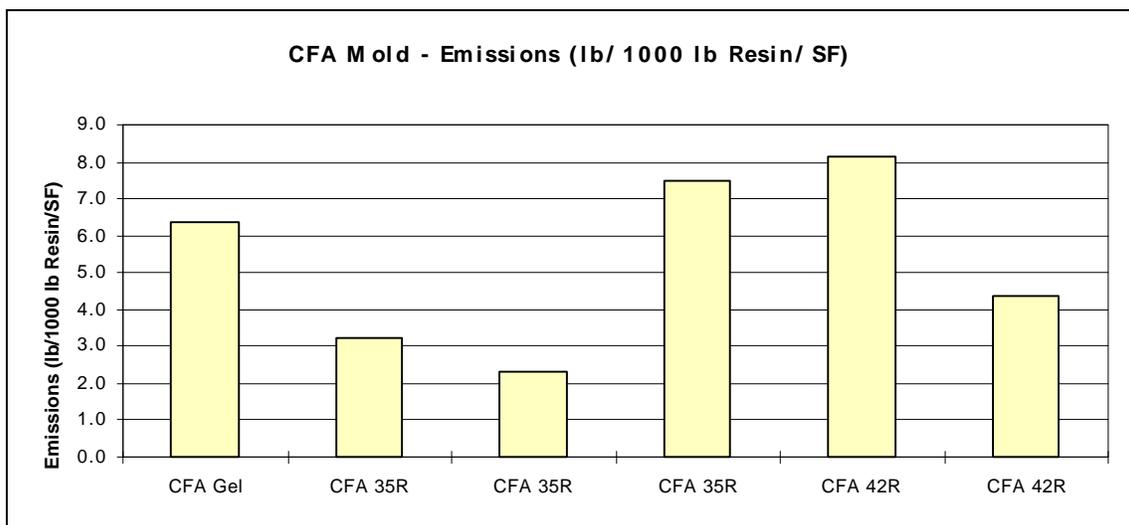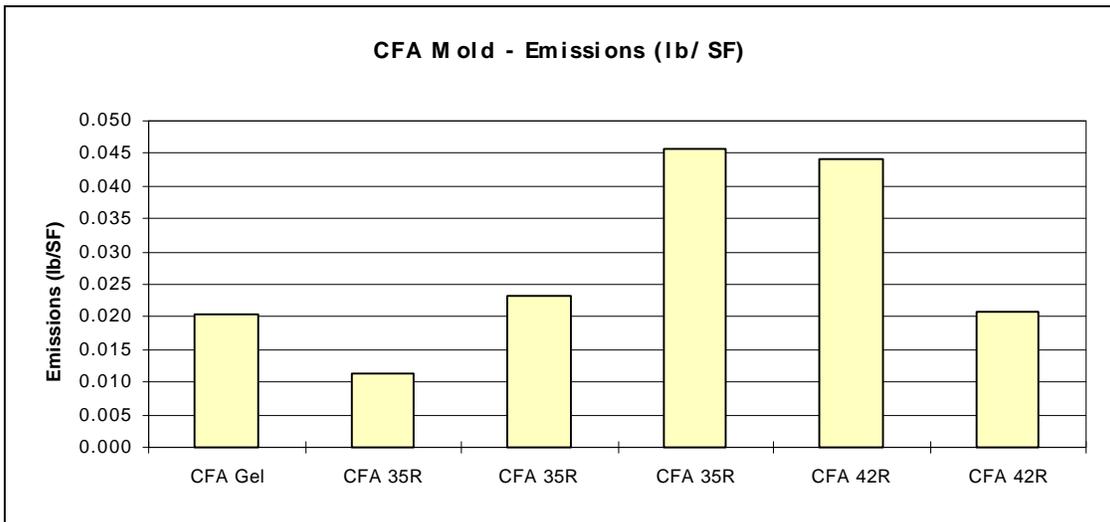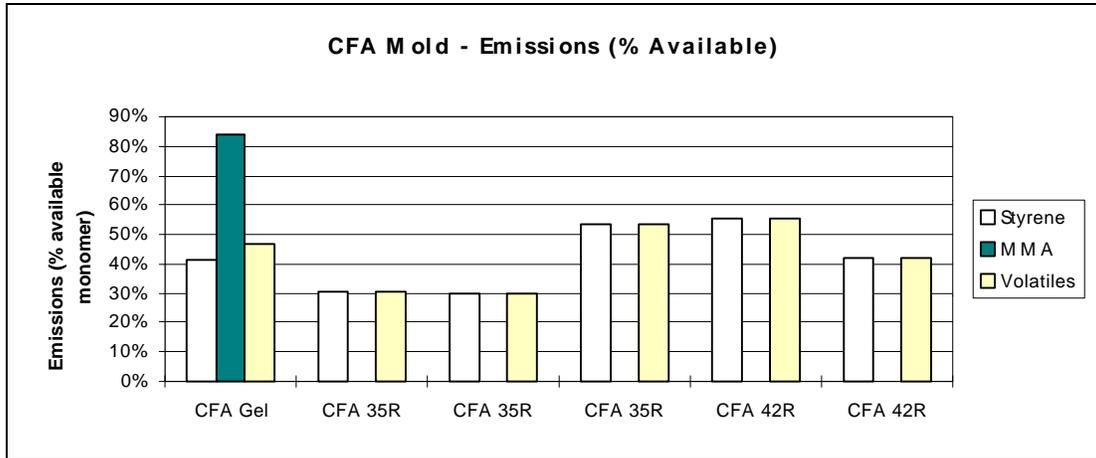
prove to be adequate for measuring the small quantities of resin (on the order of only 3.5 lb) used to laminate the CFA mold. Thus, the precision of the scale used for resin and gelcoat led to some results from CFA mold testing that were more variable than results from boat testing.

2.4 Results of Gelcoat Application Testing

All gelcoat application was done to a uniform thickness of 20 mils with a gelcoat containing 32 percent styrene and 5 percent MMA. A preliminary test run (NMMA-6-P) was made using a U.S. Marine production gelcoat supplied by the same supplier for the test gelcoat. Although the production gelcoat had different styrene content (approximately 31 percent), the results generated were included in this report because they are very consistent with the other results from gelcoat testing in this study (Figure 2-6).

Results for boat gelcoating are presented in terms of losses of styrene, MMA, and total volatiles (Figure 2-6). The total emissions measured for the deck and two hull sizes are consistent (especially for styrene and total volatiles), with slightly greater emissions resulting from gelcoating the hulls, and the greatest emissions resulting from gelcoating the larger hull (Table 2-3). The most notable finding of this testing is the relative contribution to emissions of the individual constituents in the gelcoat. From 60 to 80 percent of the MMA in the gelcoat is lost as emissions in the gelcoat process. MMA is more volatile than styrene and, thus, is lost at a much greater rate than the styrene. Only one test run resulted in MMA losses of less than 60 percent of available MMA. That run (NMMA-6-1) was discarded from the average values presented in Table 2-3 as unrepresentative because of variability of the GC response factors.

Figure 2-6
Gelcoat Emissions as Percent of Available Volatiles
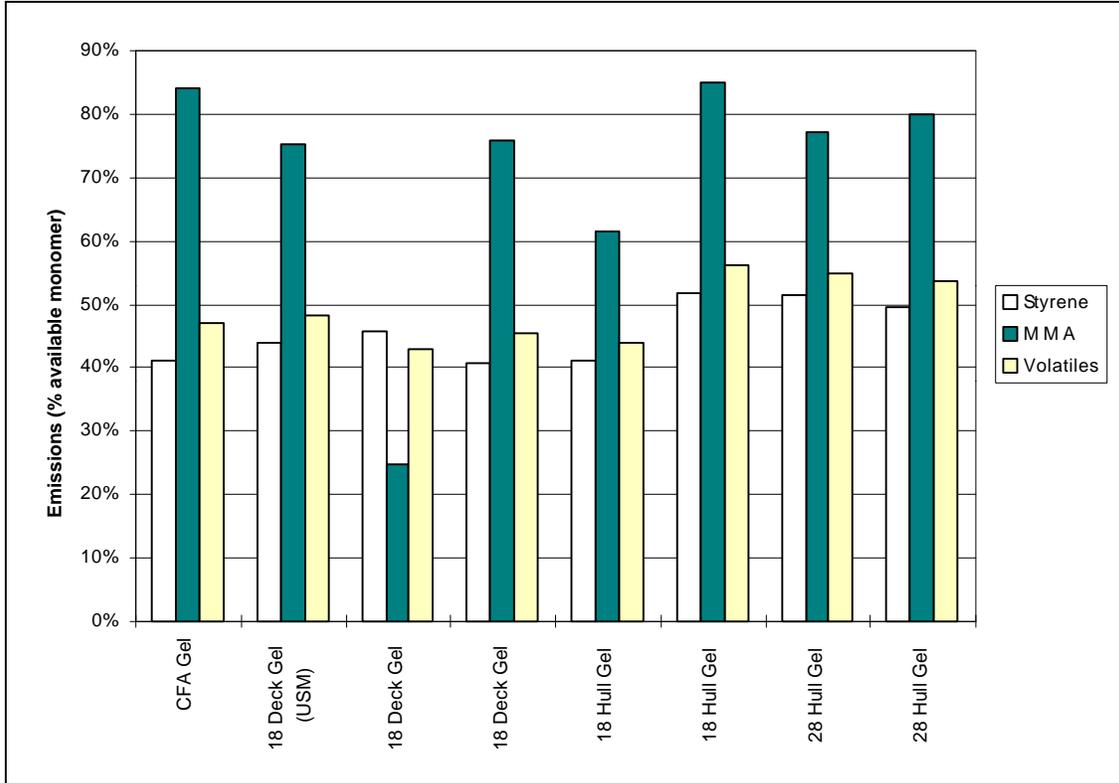
Table 2-3
Emissions from Gelcoating as Percentage of Available Volatiles

	Gelcoat Use (lb)	Percent of Available Styrene	Percent of Available MMA	Percent of Available Volatiles
18-ft Deck	20.0	42.3	75.6	46.9
18-ft Hull	25.7	46.4	73.2	50.0
28-ft Hull	65.7	50.4	78.6	54.3

The results from the first test run on the 18-ft deck after the preliminary test using gelcoat (the second run for the 18-ft deck) yielded a loss of available MMA that was substantially less than all other measurements made during all other gelcoat test runs, only about 25 percent compared with 60 to 85

percent of available MMA. Excluding that one run (NMMA-6-1) provides an average MMA loss of 75.6 percent of available MMA, a value that is very consistent with the MMA loss values for the 18-ft and 28-ft hulls. The average styrene loss for this test was relatively unchanged as a result of excluding that one run; likewise, the total volatile loss was relatively unchanged, owing to the contribution of styrene losses to the total volatile loss.

Gelcoating results evaluated in terms of loss per unit mold surface area and normalized emissions (i.e., emissions per unit mass of resin per unit mold surface area) show some interesting trends (Table 2-4 and Figure 2-7). As would be expected, the emissions from the 18-ft molds are essentially equal, owing to nearly equal resin use and surface area. Normalized emissions appear to be inversely related to mold area, assuming the same thickness of the gelcoat is applied. Normalized emissions show the general trend of increasing emissions with decreasing mold surface area. This trend was also evident from the emission testing for resin lamination.

Table 2-4
Total Emissions from Gelcoating Related to Mold Surface Area

	Gelcoat Use (lb)	Mold Area (ft²)	Emissions (lb/ft²)	Emissions (lb/1000 lb/ft²)
18-ft Deck	20.0	171.09	0.0228	1.14
18-ft Hull	25.7	220.5	0.0261	1.03
28-ft Hull	65.7	454	0.0389	0.59

Figure 2-7
Emissions from Gelcoating Related to Mold Surface Area
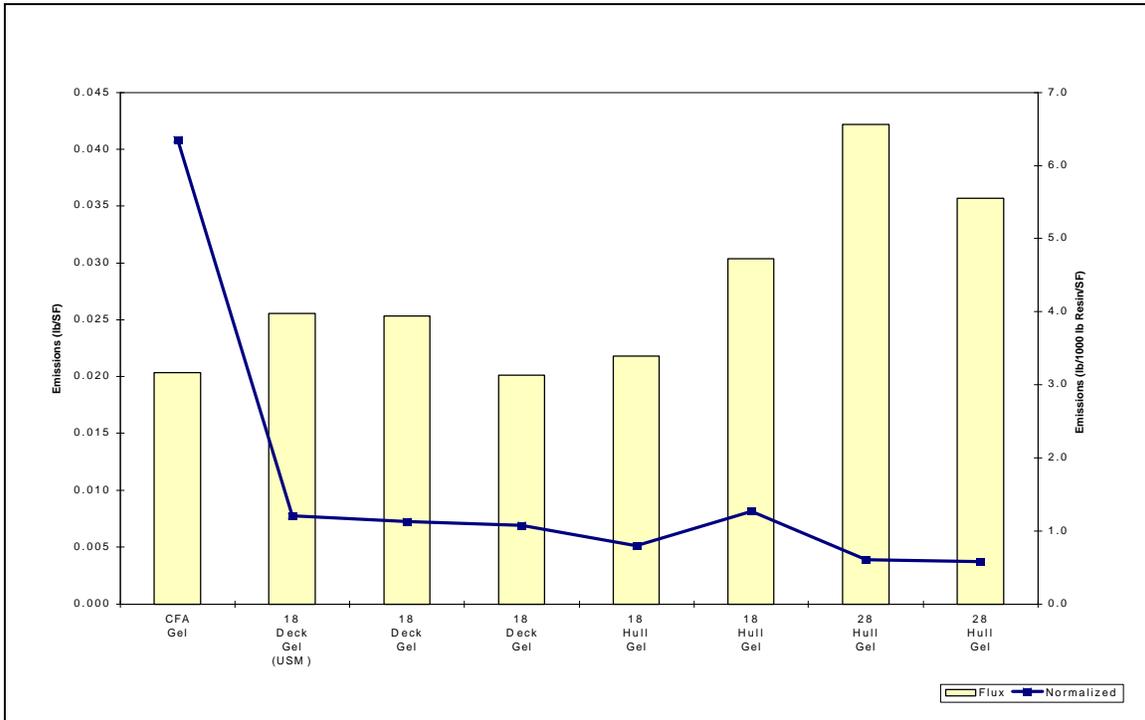
2.5   Results of Resin Lamination Testing

Testing was conducted during lamination of three mold size and shape combinations selected to be representative of the majority of resin use in the industry. Because the quantities of resin used for each test are much greater than those used in previous testing, the results were very reproducible (Table 2-5).

Figures are provided to illustrate the tabulated data. All tests are shown in the figures and are grouped by resin (styrene content) to allow comparison of the results across the different mold sizes and shapes.

Table 2-5
Emissions Measured During Resin Lamination

Test	Resin Use (lb)	Emissions		
		Percent of Available Styrene	Flux (lb/ft²)	Normalized (lb/1000 lb/ft²)
18 Deck 35 R	124.6	12.9	0.0130	0.11
18 Deck 35 R FC	114.7	11.9	0.0092	0.08
18 Deck 42 R	111.8	21.1	0.0284	0.25
18 Deck 42 R FC	122.2	13.4	0.0125	0.10
18 Hull 35 R	144.5	14.8	0.0143	0.10
18 Hull 35 R FC	141.7	10.8	0.0072	0.05
18 Hull 42 R	142.9	20.7	0.0272	0.19
18 Hull 42 R FC	154.9	11.4	0.0089	0.06
28 Hull 35 R	354.4	17.3	0.0234	0.07
28 Hull 42 R	304.2	23.3	0.0357	0.12

2.5.1 Emissions as Percent of Available Styrene

Figure 2-8 presents the data for emissions as a function of available styrene. In each set of test runs for a given mold size and shape, the same pattern of emissions is seen: the emissions from the 42 percent styrene resin lamination are greater than the emissions from lamination using 35 percent styrene resin, and the use of a flow chopper to apply the resin does result in less emissions. The latter effect is likely the result of not atomizing styrene in the spray up process. Based on these measurements, the effect of flow chopper use on emissions is greater for the higher styrene content resins.

The greatest emissions in terms of percent available styrene were measured for the larger mold size and the greater styrene content resin. An average loss of 23.3 percent of available styrene was measured from laminating the 28-ft hull with 42 percent styrene resin. Only 17.3 percent loss was measured for the same hull using 35 percent resin. Because this format of presenting

Figure 2-8
Emissions from Lamination as Function of Available Styrene

emissions should account for differences in the resin styrene content, the results indicate that emissions are not directly proportional to resin styrene content, as might have been inferred from an emission factor based on percent available styrene.

The comparisons become clearer when the same data are reviewed in terms of the various molds and tests for the different resins. Figure 2-9 presents emissions as a percentage of available styrene in the resin for the two resins tested. One observation from these results is that emissions as a percentage of available styrene for a given styrene content in the resin increase with surface area of the mold for surface areas substantially greater (i.e., the 28-ft

hull). This trend is apparent for the two styrene content resins tested. Also, the use of a flow chopper to apply resin reduces the percentage of available styrene emitted for a given mold size or shape. Greater reductions are noted for the greater percentage styrene content resin, but in general, reductions of 8 to 45 percent are noted: from about 12.9 percent available to 11.9 percent available for the 35 percent styrene resin (18-ft deck) and from 20.7 percent available to 11.4 percent available for the 42 percent styrene resin (18-ft hull).

Figure 2-9
Comparison of Results by Test
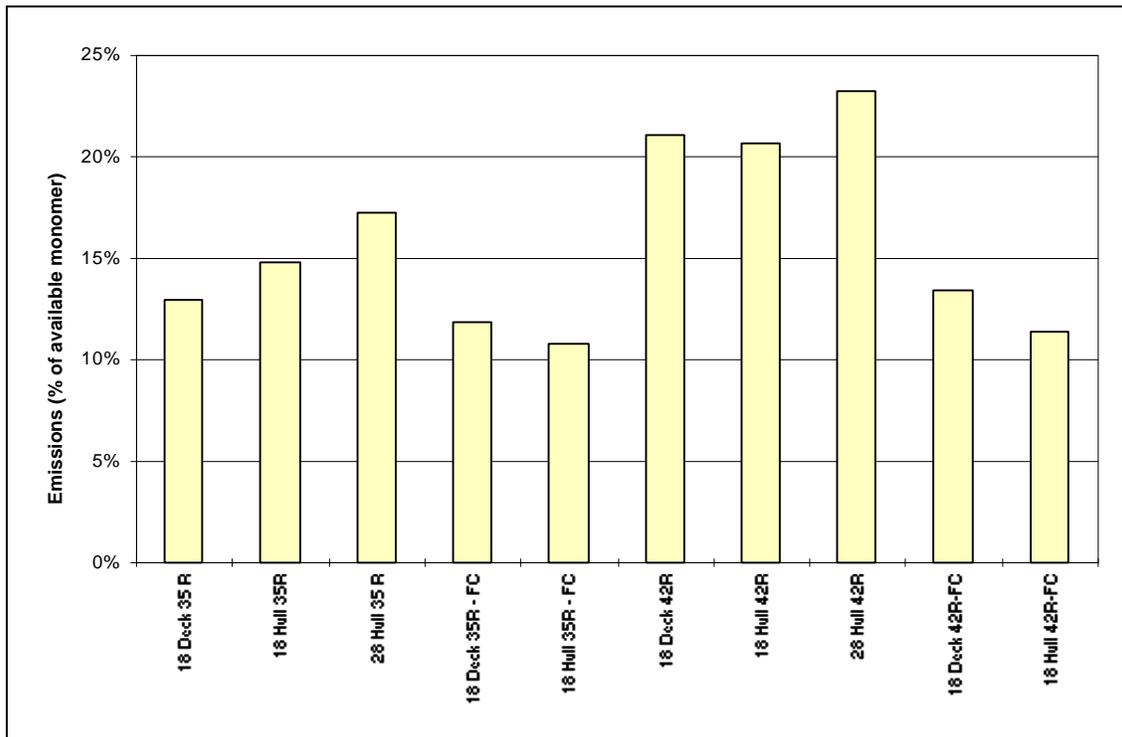
2.5.2 **Flux Emissions**

Emissions per unit area of mold surface (Figure 2-10) show the consistency of the runs made for testing and indicate general trends in the data. For example, emissions per unit surface area increase with the increase in resin styrene content. Also, the results are fairly consistent for the two 18-ft mold types, despite the difference in configuration. The hull is a concave mold and the deck (a bow rider design) has convex character.

Figure 2-10
Emissions from Resin Lamination as Flux Measurement
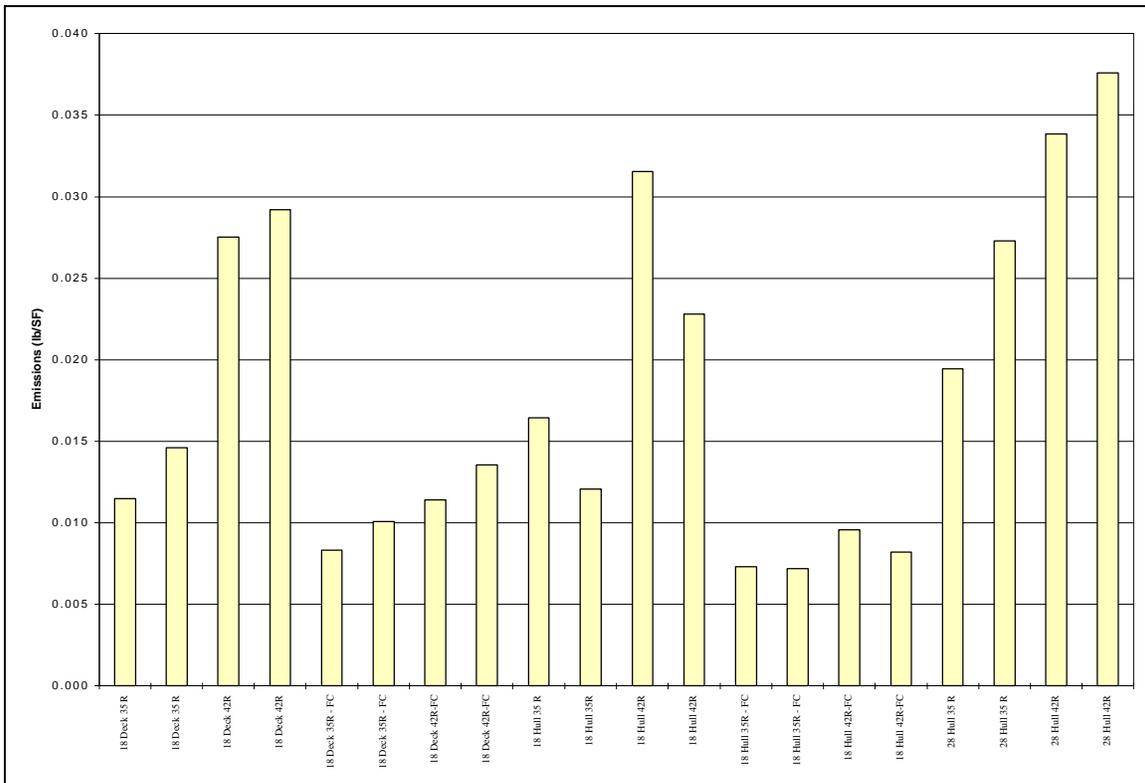
The same data, reduced to averages for each test set, are presented in Figure 2-11 for the two different styrene resins tested. These results again illustrate that emissions from the 42 percent styrene resin are greater than the

emissions from the 35 percent styrene resin lamination. In this case, because the mold surface areas are more nearly equal, flux emissions from the surface of the two 18-ft molds are almost equal. Figure 2-11 also shows that emissions from lamination using a flow chopper are less than the baseline cases.

Figure 2-11
Average Emission Flux Measurements for Two Resins
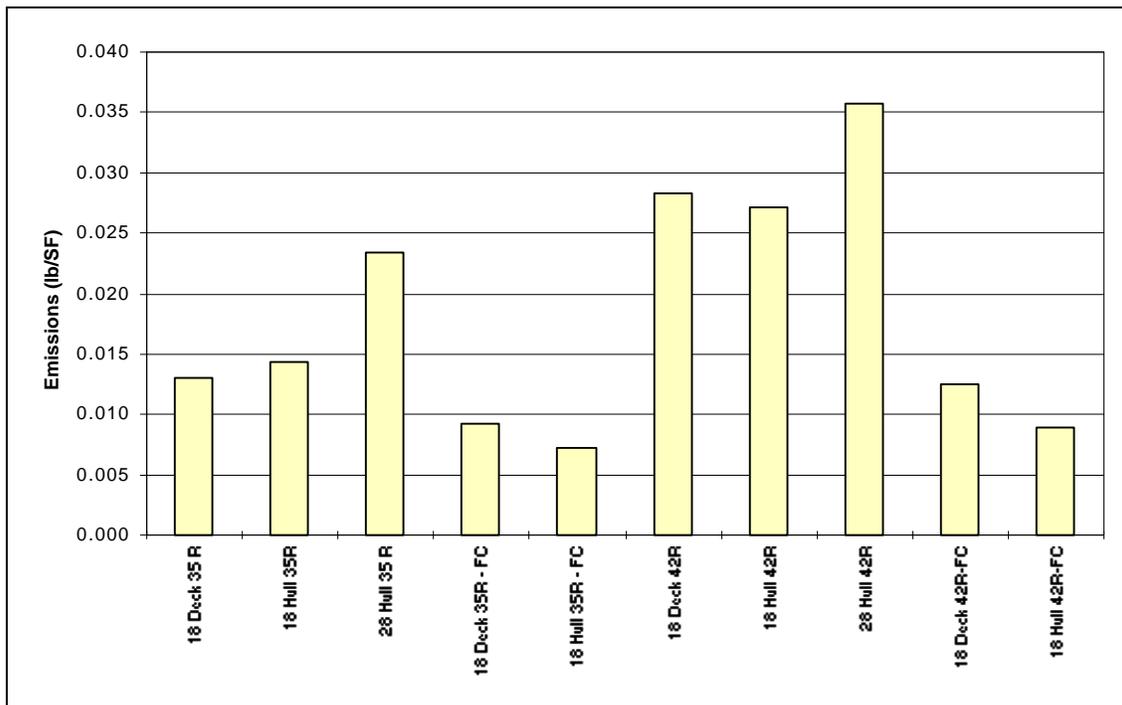
2.5.3   Normalized Emissions

Figure 2-12 compares results from all resin lamination test runs presented as normalized emissions (mass of emissions per mass of resin per surface area). For both resins, the normalized emissions decrease with increasing surface area, indicated by the 18-ft deck to the 18-ft hull to the 28-ft hull. Normalized emissions were about 80 percent greater from lamination with 42 percent styrene resin. Similar trends are noted for the emissions from lamination using a flow chopper; normalized emissions decrease with increasing mold

surface area and are always less than the normalized emissions for the corresponding spray up operation.

The differences between emissions generated using spray devices and those generated using flow choppers can be seen in Figure 2-1, which compares the concentration traces for 18-ft hull and deck mold lamination using two different styrene content resins and these two application methods. The difference in the concentration profile is due to the application devices. The utility of the flow chopper in reducing the amount of styrene atomized in application is much greater for the higher styrene content resin. As Figure 2-1 illustrates, the concentration tail after resin is applied is nearly identical for these two application methods.

Figure 2-12
Normalized Emissions from Resin Lamination
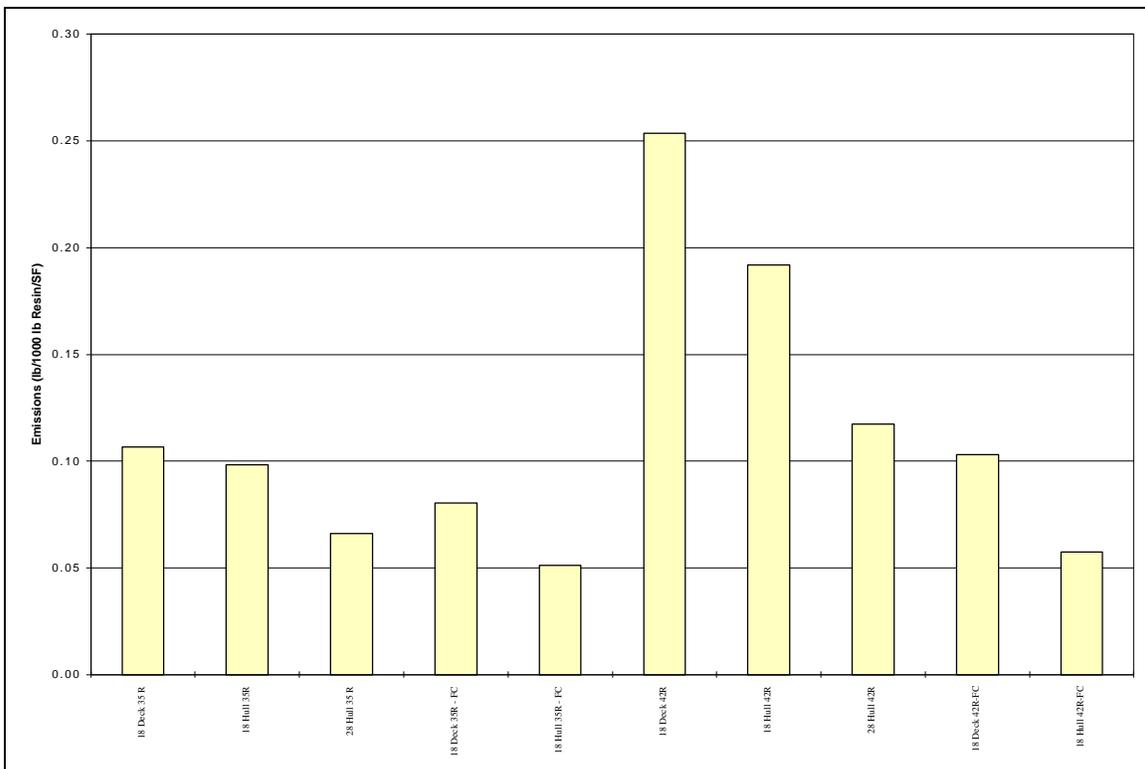
3.0 CALIBRATION AND SAMPLING PROCEDURES

The extensive battery of tests conducted and measurements made for this program includes those that were repeated routinely, either daily or during every test run, and those that were repeated only once or twice over the course of the whole program (Table 3-1). This section describes the procedures for all the tests conducted and measurements made during this program, including QC procedures (calibrations) and QA procedures followed to produce data for assessing the quality of the other measurements. The procedures are presented in terms of those associated with the process of manufacturing the part (i.e., hull or deck) and those associated with the measurement of emissions. Additional measurements (i.e., of air flow over the mold and styrene recovery) and data handling are also addressed in this section.

Table 3-1
Measurements During Test Program

Measurement	Designation	Frequency
THC Concentration	Method 25A	Continuous
Styrene (MMA) Concentration	Method 18	Intermittent (6-15 min intervals)
Wet Laminate Thickness	Wet Mil Gauge	Each Test Run
Wet Film Thickness	Wet Mil Gauge	Each Test Run
Styrene (MMA) Content	Manufacturer's Method	Per Batch Delivered
Gel Time	U.S. Marine Method	Per Batch Delivered
Resin Flow Rate	Spray Gun Calibration	Pre/Post Test Daily
Air Flow	Hot Wire Anemometer	For Each Mold
Air Temperature	Exhaust Gas Temperature	Continuous
Exhaust Flow Rate	Vent Stack Air Flow Rate	One traverse set per test; continuous point measurement
Styrene Recovery	Material Balance/Method 25A	Pre/Post Program
Resin/Gelcoat Weight	Precision Balance	Pre/Post Test; continuous measurement

Two test runs were made most test days; the number of tests completed in a day was dictated by the duration of the test and the availability

of material, molds, and personnel to construct the parts. On some days, only a single test run was completed, while on other days, as many as three test runs were completed. The procedures implemented most test days include the following:

- Morning spray equipment calibration;
- Morning leak check and calibration of the THC analyzer and the GC;
- Measurements made during the test runs, including THC, styrene and MMA (using the GC), flow rate, weight of material (resin or gelcoat) used during the run, and temperature;
- Post-test quality control measurements (calibrations);
- Measurements for second test run (THC, styrene and MMA, flow rate, weight, and temperature);
- Post-test quality control measurements; and
- Evening spray gun flow rate calibration.

Additional tests conducted include measuring the rate of air flow over the mold and mass balance styrene recovery checks (QA).

3.1 Process Procedures and Measurements

The procedures used to apply the resin were those used by the skilled U.S. Marine staff in applying gelcoat or resin/glass in the manufacturing operation. Resins and gelcoat selected for this program had characteristics typical of industry use and meeting the goals of this program (Section 1.3.5). Staff used to manufacture molds and to train lamination staff performed all gelcoating and lamination during this program. Additional personnel assisted when glass was rolled out or woven roving added to the mold.

3.1.1 Application Procedures

After the morning calibrations were completed, monitoring of air flow was established, materials to be applied were weighed, and lamination (by spray up or flow chopper) or gelcoating of a part in the TTE commenced. Skilled operators applied resin and gelcoat as they would in normal production. The operators measured laminate and gelcoat thickness periodically as the material was applied, using a chop mil gauge for laminate thickness and a gelcoat mil gauge for gelcoat thickness. During the application of both materials, multiple readings were taken at three locations along the length of the mold as the operators fabricated the part. The operators did not record gauge readings but applied material to the desired thickness, in accordance with normal operating procedures.

Gelcoat was applied using spray guns with a distance of 18-24 in. from spray tip to mold surface for smaller (18-ft) parts. The distance was greater for gelcoating the 28-ft hull mold, reaching 4-5 ft at the greatest distance from the application equipment to the keel of the hull. When gelcoating, a fog coat was applied first to one side of the mold and then a thicker layer was applied to bring the coating to a nominal thickness of 20 mils. Using typical gelcoating procedure, the operator checked the gelcoat thickness several times in at least three locations on each side of the mold to ensure uniform thickness. After one side was coated, the mold was rotated, and the process was repeated to coat the other half of the mold surface. Complex portions of some molds, such as encountered on the 18-ft deck mold, were coated using a cup and brush technique. These portions were typically inaccessible with the spray equipment.

A similar procedure was used to apply resin and glass to the 18-ft hull and deck and the 28-ft hull molds. In this procedure, though, a skin coat of

resin and glass of about 90 mil thickness was applied first and allowed to cure almost entirely before applying additional layers of the laminate. Additional layers were then added by alternating resin/glass chop and resin/woven roving. The chopped glass was rolled out at every layer. The laminate thicknesses for the hulls and decks were much greater than the laminate thicknesses used in previous studies. For example, a laminate thickness of 414 mils was used in the bottom of the 28-ft hull (including three layers of woven roving, each about 48 mil thickness), and a thickness of 198 mils was used for the sides and transom of the same hull (including one roving). A 0.010-in. thickness gauge was used to make the measurements.

3.1.2 Spray Equipment Calibration

The spray gun resin or gelcoat flow rate was determined at the beginning of every test day and confirmed at the end of every test day, that is, before the first test and after the last test. The spray equipment flow rate was adjusted (resin pump pressure was adjusted and spray tip sizes changed) by the operator to provide the normal resin and gelcoat output for manufacturing operations, and the flow rate was recorded. The flow rate calibration consisted of spraying resin (or gelcoat) into a pre-weighed container for 15 seconds, recording the material weight, and calculating the rate in pounds per minute. For spray-up application, the glass content was adjusted to the required resin flow rate; after the resin flow rate was established, the chopper speed was adjusted to provide the proper glass ratio. The spray pattern was evaluated by the experienced operators by spraying resin and glass onto a cardboard panel. Adjustments were made based on the visual pattern to achieve the desired result.

The resin/gelcoat-to-catalyst ratio was calibrated by comparing the catalyst volume measurement to flow rate and adjusting the catalyst ratio by the slave pump setting. Both resin and catalyst are delivered to the applicator head by positive displacement pumps. Because the air-actuated piston pumps deliver a fixed amount of material with every stroke, the amount of catalyst delivered to the applicator head can be accurately set based on the stroke count. The amount of catalyst delivered to the applicator is very small compared with the amount of resin delivered, so the amount of resin is set first and calibration completed. Then the stroke count of the resin pump is set to the desired catalyst ratio. The catalyst ratio is adjusted after application of the skin coat and then these stroke count settings were maintained throughout each day.

3.1.3 Gel Time

Gel time was measured on site for each batch of resin used (Table 3-2). The procedure used to measure gel time (Appendix D) is the same procedure used by U.S. Marine in determining gel time for production resin and gelcoat. Gel time for gelcoat was determined using a 2 percent 925 clear catalyst (MEKP); a gel time of about 16.5 minutes is typical for the gelcoat. Two gel times are common for lamination, one for the skin coat and another for the bulk of the lamination. The skin coat gel time for the 35 percent styrene resin was about 18 minutes using a 2 percent Red 925 MEKP catalyst; the remainder of the lamination was done using a gel time of about 23.2 minutes with a 1.5 percent Red 925 MEKP catalyst. The latter materials achieved a peak gel temperature in 26 (for the 1.5 percent catalyst) to 34 minutes (for the 2 percent catalyst). Comparable gel measurements were made for the 42 percent styrene resin.

Table 3-2
Gel Time Results

	1.5% Catalyst	2% Catalyst	2.5% Catalyst
Gelcoat			
Gel time @ 77°F		16:30	
35% Resin			
Gel time	23:13	17:59	15:38
Gel time to 150°F	6:05	5:06	3:09
Time to Peak Temperature	33:57	26:18	22:11
Peak Temperature (°F)	350	360	376
42% Resin			
Gel time	23:29	18:42	16:38
Gel time to 150°F	6:17	5:05	5:04
Time to Peak Temperature	35:55	28:47	27:08
Peak Temperature (°F)	320	352	367

3.1.4 Styrene and Methyl Methacrylate Content

Styrene and MMA content of the resins and gelcoat used during this study were determined by the resin suppliers: Alpha/Owens-Corning for the resin and Cook Composites and Polymers for the gelcoat. Industry procedures were followed and certifications of styrene and MMA content provided (Table 3-3). Material safety data sheets with material certifications are in Appendix E.

Table 3-3
Styrene and MMA Contents

Material	Styrene Content (wt. %)	MMA Content (wt. %)
Laminating Resin (35 R)	35.1	0.0
Laminating Resin (42 R)	42.2	0.0
Test Gelcoat	32.0	5.0
Production Gelcoat (USM)	30.95	4.95

3.2   Emission Testing Equipment and Procedures

This section describes the equipment used to sample emissions from the enclosure and to measure other critical test parameters such as flow rate from the enclosure, temperature of the exhaust stream, and amount of resin applied. QC checks made on the sampling system are also presented in this section.

Samples were collected from the enclosure's exhaust duct through Teflon® sample tubing at ambient temperature using a sample pump. This sample was fed continuously to a THC analyzer and to the GC used to speciate the organic compounds in the exhaust stream. The THC data were collected continuously and recorded in a computer data acquisition system (DAS) through a Dianachart data logger. GC data were collected separately.

The following data were collected continuously:

- TTE outlet THC concentration,
- TTE inlet THC concentration,
- Velocity pressure head in the exhaust duct,
- Temperature of the exhaust stream, and
- Weight of the gelcoat or resin used.

3.2.1   Leak Check and Instrument Calibration

Leak checks and bias checks were incorporated into the calibration and response factor procedures, respectively. Calibration gases were introduced at the probe inlet, and calibration responses were obtained using the same procedures as those used for sample responses. Certifications for all gas

standards are included in Appendix F. No vacuum leak checks were performed because any leaks, if present, would be small enough to be "calibrated out" and stable enough to have a negligible effect on post-test drift measurements. Any bias introduced by the system was similarly subsumed in the response factor determinations because they were performed with the entire sampling system.

Instrument calibration checks were also made at the instrument and the results compared with the overall calibration checks made at the sample probe tip. The two sets of results were consistent, indicating that there was little or no bias in the sampling system. Checks by the EPA during their technical system audit verified the findings of the NMMA checks.

3.2.1.1   Total Hydrocarbon Analyzer

THC was measured at the outlet and inlet of the enclosure using an FID in accordance with EPA Method 25A (Appendix A). Analysis of the outlet gas stream was made using a Thermo Electron Model 51H THC analyzer. A Ratfisch Model 52RF analyzer was used to monitor THC content in the inlet air to the enclosure. A second Ratfisch was held on stand-by in case one of the other instruments failed. Both instruments were calibrated using the same procedure.

Before testing each day, the calibration of the FID was verified using zero, low span (30 percent), mid-span (60 percent), and 90 percent span gases. Only one detection range, 1000 ppmv as propane, was used, which covered concentrations of styrene from 0 to approximately 416 ppmv. Calibration was simplified by using the DAS instead of recalibrating the two instruments. That is, instead of using adjustment potentiometers on the instruments themselves, the response signal to the DAS computer was adjusted in the computer program. This approach, which basically acknowledges that the

DAS is an integral part of the entire sampling, analysis, and data acquisition system, allowed more rapid calibration of the system each morning. An advantage, beyond mere simplification of the process, was that calibration incorporating the DAS allowed calibration of the entire system, including sampling lines, instrument, and data systems, incorporating potential biases created by sample extraction equipment, instrument response, and the DAS into a single system response. The acceptable calibration error of less than 10 percent was met for both instruments for all tests (Section 4.1.1).

The FID was calibrated with propane. Instrument response factors were periodically developed for styrene and MMA by analyzing known concentrations of the target compounds in a manner identical to that employed for propane calibration. This procedure generated a correlation of relative response of the compounds on the THC instrument, a factor needed to compare the results of Method 18 sampling with Method 25A sampling.

After the first test of the day, the instrument drift of the analyzer was checked using zero, 30 percent, and 60 percent span gases. When the drift was within the acceptable range, testing proceeded; otherwise, the instrument was recalibrated. The post-test calibration drift was recorded before any recalibration took place. The results of these measurements are reported in Section 4.1.1.

Printouts of raw continuous emission monitoring data are included by run in the field data bound separately. Monitoring data printouts with reduced data are included with other calculations (Appendix C).

3.2.1.2   Gas Chromatograph

Concentrations of the two specific organic compounds expected in the exhaust from the enclosure (styrene and MMA) were measured to provide speciation of their emissions during gelcoat operations and to provide a check on the Method 25A emission measurements using Method 18. Specific concentrations of styrene and MMA were determined using periodic measurements by GC using a Hewlett Packard Model 5890 with a Model 3396 Series II integrator. A Supelco GP 10% 1,2,3-tris(2-cyanoethoxy)propene on 80/100 Chromosorb PAW column (1/8-in diameter X 6 ft long stainless steel) was used for these analyses. Hydrogen at 25 psi was provided to the instrument for the flame; air (at 33 psi) and nitrogen (at 50 psi) were also provided to the instrument to support the flame and as a carrier gas (35 cc/min) for the sample. The instrument was maintained at 130°C for all GC analyses.

Measurements and calibration were conducted in accordance with EPA Method 18 specifications (Appendix A). Sample gas was continuously fed to the GC using the sampling system from the enclosure exhaust duct. Part of the sample stream was sent to the THC analyzer, with another portion of the stream flowing to the GC. At least GC four measurements per hour were to be made in accordance with the QAPP; more often, data were collected every 6 to 8 minutes.

The GC was calibrated according to Method 18 procedures using styrene and MMA to indicate the retention time and the area counts. Styrene gas standards in cylinders were used to provide styrene for these calibrations. MMA standards were prepared in Tedlar® bags (Appendix G) using the procedure detailed in Method 18. After establishing the retention time for styrene and MMA, the integrator was programmed to identify the two compounds (by retention time) and used the response factor determined daily to calculate the

concentrations of each compound. Area counts for the instrument responses were recorded and concentrations calculated off-line in spreadsheets. A linear relationship between concentration and area count was generated for each calibration to calculate concentrations. (These calibration "curves" are included with the calculations in Appendix C.) All chromatograms generated during daily tests have been bound separately with the other field data. Records and reductions for every run are included in Appendix C.

Day to day calibration checks met the acceptance criteria or the instrument was recalibrated. Results of instrument calibration are presented in Section 4.1.2. The audit of the GC system that the EPA conducted is discussed in Section 4.7.

3.2.2 Flow Rate Measurements

Air flow rate from the enclosure was measured using EPA Method 2 protocols once per test. Flow rate was also monitored continuously at a single point in the TTE exhaust duct using a standard (Type L) pitot tube by recording the velocity pressure head at the centroid of the duct. The pressure head was logged through the Dianachart data logger to the computer DAS with other parameters, such as temperature, resin weight, and THC concentrations at the inlet and outlet to the enclosure. The Method 2 velocity traverse was performed for each test run using the same standard pitot tube to monitor air flow through the duct.

A velocity for each recorded THC measurement was calculated based on a ratio of the average pressure head readings. The constant velocity monitor reading at the time of the traverse was noted. This reading was scaled to the instantaneous reading (recorded in the DAS) and to the flow rate measured

using a complete traverse. The average of each calculated 1-min flow rate reading based on 1-min velocity head readings was used in calculating an average volumetric flow rate over the entire sampling period of the test run. The change in flow rate over the course of any test run was less than 3 percent.

3.2.3   Temperature

The type K thermocouple used for DAS and flow measurements was calibrated on site at two points: ice bath (32°F) and boiling water (212°F). Air temperature within the enclosure was monitored continuously at the location of the fixed pitot. Therefore, this temperature reflects the temperature at the sampling location rather than the temperature within the enclosure. Air flow velocities within the exhaust duct were approximately 30-35 ft/sec. The TTE exhaust temperature was therefore measured within two seconds of leaving the enclosure. The temperature of the well-mixed TTE exhaust provided a better measurement of the average TTE temperature than a single fixed point within the TTE because of the short retention time in the exhaust duct and the small temperature differential between ambient and exhaust air. The temperature was monitored continuously using the DAS calibrated at two points.

3.2.4   Weight of Material Used

The weight of the resin or gelcoat used during a test run was determined by weighing the container of material on a platform balance immediately before and after application to the mold. The balance was equipped with an analog output that allowed changes in weight to be tracked on the DAS.

A small degree of variability in the weight measurement was noted during the testing on the CFA mold, where only 3.5 to 10 lb of resin were used.

The variability resulted from the movement of the ancillary equipment associated with the resin and catalyst delivery systems. As indicated by the weigh scale calibration checks (Section 4.6) and audit (Section 4.7.2), the scale met the desired performance criteria and provided accurate measurements of the resin and gelcoat use during testing on boat parts.

The weight of the catalyst was determined from the resin (or gelcoat) weight and the established catalyst-to-resin ratio. These ratios were set based on stroke count of the positive displacement piston pumps used for both materials. The amount of catalyst was insignificant compared to resin or gelcoat use.

The balance used to determine weight of resin and gelcoat used during lamination was calibrated by Weigh Tronics in Seattle before it was delivered to the site. All adjustments were made at the signal output and DAS; no adjustment was made to the scale that would have affected its calibration. Calibration certification is included with other certifications in Appendix F.

Calibration of the scale was checked periodically during the testing program. These results are presented in Section 4.6. The precision and accuracy of the balance was checked during the on-site technical system audit conducted by the EPA. The results of this audit are presented in Section 4.7.2.

3.3   Air Flow Over the Mold

Air flow over the mold in the TTE was measured to enhance the documentation of the experiments conducted, but no adjustment was made to the rate of air flow through the enclosure based on the measurement. The more important adjustment was the flow rate through the enclosure to simulate the

number of room volume exchanges found in the U.S. Marine production area (an integral part of the TTE design). The velocities over the parts were measured merely to provide a record.

To support the validity of the measured velocities over the parts, measurements were made (with a hot wire anemometer) early in the test program to determine the range of velocities over parts encountered in the production environment. Air flow velocities in a production lamination area used for laminating large boats and large parts for those boats ranged from 20–25 ft/min near the air pick-ups at the exhaust plenum to 34–40 ft/min in the center of the lamination area. (In this production area, air was supplied through air handlers at one side of the room and exhausted from pick-up plena on the opposite side of the room.) Velocities near 200 ft/min were measured on covered molds (convex architecture) near the exhaust from the air handlers servicing the lamination area. This higher velocity was not typical in the lamination area.

Measurements made in the testing enclosure showed that velocities of 20-24 ft/min were typical for the enclosure. These velocities were typical of measurements for induced draft environments, such as those found nearer the exhaust plenum in the lamination room. Measurements on the part (near the door to the enclosure) showed that the bulk velocity into the enclosure was approximately 40 ft/min. (Velocities at the NDOs to the TTE were much greater than the required 200 ft/min, as noted in Section 1.3.1.)

Air flow over the mold was first evaluated for the 18-ft deck mold. Measurements at five locations on the mold surface ranged from 20-24 ft/min on the lower portion of the mold to 30-35 ft/min at the upper region of the mold, nearer the air intakes for the enclosure. Velocities were checked on the 28-ft hull mold at seven locations; velocities ranged from 20 to 36 ft/min. Measurements

were made parallel to the surface of the mold, where the maximum velocity was noted on the readout from the hot wire anemometer. Sketches from the log book showing locations of measurements and results are found in Appendix H.

During the site audit by the EPA and its contractor Midwest Research Institute (MRI), air velocity measurements at the mold surface were made to verify that the velocity was in the range typical of the industry (and plant) practice. Measurements made by MRI (Appendix H) corroborate the measurements made on the molds.

Velocities were not measured during each test or run. These velocities were not key measurements of the program; further, the velocities would not be expected to vary during the program because the flow rate through the enclosure was not a variable during this program and the geometry of the molds did not vary.

3.4   Mass Balance Styrene Recovery Check

In accordance with the QAPP, styrene evaporation tests (the towel tests) were conducted to evaluate the capture and recovery of styrene by the sampling system. Two tests were completed, one at the initiation of the testing program and one at its conclusion.

A covered container was loaded with a large pan, a collapsible clothes drying rack, towels, and a gallon of styrene and was weighed on a precision scale outside the TTE. (The scale used for this test was used by RTI in their testing to measure smaller quantities of materials.) The container was then placed inside the TTE, the rack erected in the pan, towels draped over the bars, and, with the flow rate and emissions being measured, the styrene was poured

over the towels and into the pan. A fan was used to induce flow over the towels and accelerate styrene evaporation. After about 30 minutes, the equipment was repacked into the container and the TTE allowed to clear of styrene (while emission monitoring continued). When emissions reached background concentrations, the container was removed from the TTE and reweighed.

Emissions were measured using the THC analyzer and the GC during the first styrene recovery check, but using only the THC analyzer during the second. Recoveries are based on THC results, and the sampling system's capture and recovery of styrene was assessed by comparing the quantity of styrene evaporated (determined from weight loss of the container) with the quantity of styrene measured in the exhaust (calculated from the average styrene concentration and exhaust flow rate). The results of these tests, reported in Section 4.7.4, indicate good agreement between the measured evaporative loss and the measured mass emission quantity.

3.5 Data Custody

Because all emission measurements were made using continuous monitors that vent emission streams after analysis, no sample retention was necessary, or possible. Data collected in the field include gel time, spray gun calibration, quantity of resin material used, temperature of the exhaust, static pressure of the exhaust stream, pressure head of the exhaust stream, THC concentration of the inlet stream to the enclosure, THC concentration on the outlet stream from the enclosure, and concentrations of specific compounds in the exhaust from the enclosure. Test runs are designated by day, for example, 0408-01 indicates the first run on April 8, 1997. Test numbers are designated with "NMMA" prefix, for example, NMMA-1-1 indicates test condition 1, assessment 1 (Table 1-1). Thus, a test can be identified by date or by type using

the total description: 0405-01, NMMA-8-2 indicates a second replicate of a 28-ft hull gelcoating and was the first run on April 5, 1997.

4.0   QUALITY CONTROL AND QUALITY ASSURANCE

Quality control/quality assurance (QC/QA) guidelines outline pertinent steps to be followed during the production of gas composition data to ensure the reliability and acceptance of the data generated. QC, in the context of this report, refers to a system of activities designed to achieve a level of precision and accuracy as specified in the project plan. The QC procedures are targeted at maintaining a level of quality but in themselves are not a measure of the degree of quality achieved. QA, as used in this report, refers to the system of activities implemented to measure the effectiveness of the QC system.

The QC/QA procedures implemented during this test program were presented in the *Quality Assurance Project Plan for the National Marine Manufacturers Association Baseline Emission Testing Project* (QAPP), which was approved by the EPA before the on-site sampling program. This section presents the results of the measurements taken to demonstrate adherence to the data quality objectives for critical measurements, as presented in Section 3 of the QAPP.

4.1   Concentration Measurements

The measurements taken for the characterization of THC content of the TTE exhaust gas stream were made according to the procedures of EPA Method 25A; this approach was the same as that used in previous studies, ensuring comparablity with those previous tests. Styrene and MMA concentration measurements were made according to Method 18 procedures. Previous studies have not evaluated resins containing MMA. Method 18 results are critical to speciation of THC from the gelcoat testing where these two species are measured. No other compound was identified in the Method 18

chromatograms. The QA measures and the acceptance criteria used for this test program, which were approved by the EPA in the QAPP, are presented in Table 4-1.

Table 4-1
Acceptance Criteria for Concentration Measurements

Method	Measurement	Acceptance Criteria
25A	Calibration Error	≤ 10 percent of calibration gas value
25A	Calibration Drift	≤ 10 percent of calibration gas value
18	Calibration Error	≤ 10 percent of calibration gas value
18	Calibration Drift	≤ 5 percent of calibration gas value

Note: Calibration error measurements were substituted for performance audits because no audit materials were provided for routine assessment.

4.1.1   Total Hydrocarbon Measurements (Method 25A)

Tables 4-2 and 4-3 present the results of the Method 25A calibration error and drift tests for all the test runs. Detailed results are presented in Appendix C. Both assessments of instrument performance were made before and after each test. The calibration errors presented in Table 4-2 are within the acceptance criteria presented in the QAPP. The results of instrument drift assessments demonstrate similar results; all post-test assessments are well within 10 percent of pre-test values. Based on review of these Method 25A calibration assessments, all the data presented in this report are accurate to within 10 percent of the values reported, with a variability in precision of no greater than 10 percent.

Because Shirley Wasson of the ORD during her review of the QAPP expressed concerns about the stability of styrene stored in cylinders, THC instrument calibrations were performed using propane. Response factors were then determined for instrument response to styrene and MMA in terms of

Table 4-2
Calibration Error Measurements for Total Hydrocarbon Analyzer
(Percent Actual Gas Value)

Date	Test	Run	Actual Gas Concentration (ppmv)								
			Inlet Instrument				Outlet Instrument				
			0	15	30.4	45.5	0	297	600	914	1604
10-Apr	NMMA-14-1	0410-01	N.A.	0.0	0.0	-0.7	N.A.	1.3	2.3	0.0	
11-Apr	NMMA-14-2	0411-02	N.A.	0.7	0.0	-0.4	N.A.	-0.4	1.4	-2.1	
15-Apr	NMMA-16-1	0415-01	N.A.	2.7	2.3	0.4	N.A.	-0.8	-0.1	-3.4	
16-Apr	NMMA-16-2	0416-01	N.A.	2.0	2.3	0.2	N.A.	-0.9	0.1	0.0	
2-Apr	NMMA-6-P	0402-01	N.A.	0.7	1.3	-1.5	N.A.	-0.3	-0.7	-0.3	
8-Apr	NMMA-6-1	0408-01	N.A.	-1.3	0.0	-0.4	N.A.	0.7	2.3	0.0	
11-Apr	NMMA-6-2	0411-01	N.A.	3.3	4.3	0.4	N.A.	-0.5	0.3	-0.1	
3-Apr	NMMA-4-1	0403-02	N.A.	-0.7	-0.3	0.0	N.A.	1.8	3.0	0.2	
8-Apr	NMMA-4-2	0408-03	N.A.	-1.3	0.0	-0.4	N.A.	0.7	2.3	0.0	
12-Apr	NMMA-5-1	0412-02	N.A.	2.0	1.3	0.2	N.A.	-0.6	0.3	-0.1	
14-Apr	NMMA-5-2	0414-01	N.A.	2.0	1.3	0.2	N.A.	0.7	1.9	-1.2	
10-Apr	NMMA-13-1	0410-02	N.A.	0.0	-0.7	0.2	N.A.	2.0	2.8	-0.1	
11-Apr	NMMA-13-2	0411-03	N.A.	0.7	0.0	-0.4	N.A.	-0.4	1.4	-2.1	
15-Apr	NMMA-15-1	0415-02	N.A.	2.7	2.3	0.4	N.A.	-0.8	-0.1	-3.4	
16-Apr	NMMA-15-2	0416-02	N.A.	2.0	2.3	0.2	N.A.	-0.9	0.1	0.0	
4-Apr	NMMA-3-1	0404-02	N.A.	-1.3	-0.7	0.0	N.A.	-0.3	-0.7	-0.3	
8-Apr	NMMA-3-2	0408-02	N.A.	-1.3	0.0	-0.4	N.A.	0.7	2.3	0.0	
5-Apr	NMMA-1-1	0405-02	N.A.	-4.7	-1.3	0.4	N.A.	2.5	4.8	2.8	
9-Apr	NMMA-1-2	0409-01	N.A.	0.7	0.3	0.2	N.A.	-0.8	0.2	0.0	
12-Apr	NMMA-2-1	0412-02	N.A.	2.0	1.3	0.2	N.A.	-0.6	0.3	-0.1	
14-Apr	NMMA-2-2	0414-03	N.A.	2.0	1.3	0.2	N.A.	0.7	1.9	-1.2	
10-Apr	NMMA-13-1	0410-02	N.A.	0.0	-0.7	0.2	N.A.	2.0	2.8	-0.1	
11-Apr	NMMA-13-2	0411-03	N.A.	0.7	0.0	-0.4	N.A.	-0.4	1.4	-2.1	
18-Apr	NMMA-9-1	0418-01	N.A.	0.7	1.0	0.0	N.A.	0.0	0.0	-0.1	-1.7
19-Apr	NMMA-9-2	0419-01	N.A.	-1.3	0.7	-0.4	N.A.	-0.7	0.8	0.1	
3-Apr	NMMA-8-1	0403-01	N.A.	-0.7	-0.3	0.0	N.A.	1.8	3.0	0.2	
5-Apr	NMMA-8-2	0405-01	N.A.	-1.3	4.6	-4.8	N.A.	4.7	4.8	1.1	
4-Apr	NMMA-7-1	0404-01	N.A.	-1.3	-0.7	0.0	N.A.	0.5	2.6	-0.4	
7-Apr	NMMA-7-2	0407-01	N.A.	-4.7	-3.9	0.7	N.A.	3.0	5.2	0.0	
9-Apr	NMMA-11-1	0409-03	N.A.	0.7	0.3	0.2	N.A.	-0.8	0.2	0.0	
10-Apr	NMMA-11-2	0410-03	N.A.	0.0	-0.7	0.2	N.A.	2.0	2.8	-0.1	
12-Apr	NMMA-11-3	0412-01	N.A.	-1.3	-1.3	-0.9	N.A.	2.8	3.8	0.6	
14-Apr	NMMA-12-1	0417-01	N.A.	3.3	2.6	0.2	N.A.	-0.1	0.7	-0.1	-0.1
18-Apr	NMMA-12-2	0418-02	N.A.	0.7	1.0	0.0	N.A.	-0.9	0.0	-0.1	-1.7

Table 4-3
Calibration Drift Measurements for Total Hydrocarbon Analyzer
(Percent Span)

Date	Test	Run	Actual Gas Concentration (ppmv)								
			Inlet Instrument				Outlet Instrument				
			0	15	30.4	45.5	0	297	600	914	1604
10-Apr	NMMA-14-1	0410-01	0.0	-0.4	-1.0	-4.2	0.0	-0.2	0.5	1.9	
11-Apr	NMMA-14-2	0411-02	0.0	-0.2	0.2	-0.2	0.0	0.1	-0.3	-0.1	
15-Apr	NMMA-16-1	0415-01	0.0	-0.6	-1.2	N.A.	0.0	-0.6	-1.1	N.A.	
16-Apr	NMMA-16-2	0416-01	0.0	0.0	-1.6	N.A.	0.0	-0.4	-0.2	N.A.	
2-Apr	NMMA-6-P	0402-01	-0.6	-0.8	N.A.	2.4	0.0	0.1	N.A.	0.6	
8-Apr	NMMA-6-1	0408-01	0.2	0.4	-2.2	N.A.	0.0	0.2	0.8	N.A.	
11-Apr	NMMA-6-2	0411-01	0.2	-0.8	-2.6	-0.8	0.0	0.0	0.6	-1.9	
3-Apr	NMMA-4-1	0403-02	-1.0	-1.2	-1.6	-3.8	0.0	-0.2	-0.3	1.5	
8-Apr	NMMA-4-2	0408-03	0.0	-0.4	-1.8	-2.6	0.1	-0.2	0.0	2.1	
12-Apr	NMMA-5-1	0412-02	0.0	0.8	1.6	N.A.	0.0	-1.1	-1.6	N.A.	
14-Apr	NMMA-5-2	0414-01	-0.8	-1.4	-3.2	N.A.	0.0	-0.1	0.1	N.A.	
10-Apr	NMMA-13-1	0410-02	-0.4	-1.0	-1.2	N.A.	0.0	-0.8	-1.1	N.A.	
11-Apr	NMMA-13-2	0411-03	-0.2	-0.4	-0.6	N.A.	0.0	-0.2	-0.3	N.A.	
15-Apr	NMMA-15-1	0415-02	0.0	-0.2	-1.2	N.A.	0.0	-0.6	-0.9	N.A.	
16-Apr	NMMA-15-2	0416-02	-0.2	-0.2	-1.4	N.A.	0.0	0.0	0.6	N.A.	
4-Apr	NMMA-3-1	0404-02	-1.6	-1.2	-1.0	N.A.	0.0	0.1	N.A.	0.6	
8-Apr	NMMA-3-2	0408-02	0.0	-0.2	-1.4	N.A.	0.0	-0.4	-0.3	N.A.	
5-Apr	NMMA-1-1	0405-02	-1.2	1.0	1.4	N.A.	0.0	0.3	0.4	N.A.	
9-Apr	NMMA-1-2	0409-01	0.0	-0.6	-0.6	N.A.	0.0	-0.2	0.0	N.A.	
12-Apr	NMMA-2-1	0412-02	-0.2	-0.6	-0.6	N.A.	0.0	-0.9	-1.5	N.A.	
14-Apr	NMMA-2-2	0414-03	-0.2	-2.0	-2.6	N.A.	0.0	-0.1	0.1	N.A.	
10-Apr	NMMA-13-1	0410-02	-0.4	-1.0	-1.2	N.A.	0.0	-0.8	-1.1	N.A.	
11-Apr	NMMA-13-2	0411-03	-0.2	-0.4	-0.6	N.A.	0.0	-0.2	-0.3	N.A.	
18-Apr	NMMA-9-1	0418-01	-0.2	-0.2	-1.2	N.A.	0.0	N.A.	0.0	0.5	N.A.
19-Apr	NMMA-9-2	0419-01	-1.0	-0.4	-2.0	N.A.	0.0	0.1	0.1	N.A.	
3-Apr	NMMA-8-1	0403-01	-1.2	0.8	N.A.	N.A.	0.0	N.A.	0.5	N.A.	
5-Apr	NMMA-8-2	0405-01	-3.8	-0.8	0.8	N.A.	0.0	-0.6	0.0	1.6	
4-Apr	NMMA-7-1	0404-01	-0.2	-0.6	N.A.	-1.8	0.0	-0.2	N.A.	2.3	
7-Apr	NMMA-7-2	0407-01	-2.6	0.8	-2.8	N.A.	0.0	0.4	0.9	N.A.	
9-Apr	NMMA-11-1	0409-03	-0.2	-1.2	-0.8	-3.0	0.0	0.0	0.4	-0.2	
10-Apr	NMMA-11-2	0410-03	-0.4	-0.6	-0.8	N.A.	0.0	-0.4	-0.8	N.A.	
12-Apr	NMMA-11-3	0412-01	-0.4	-2.2	-0.6	N.A.	0.0	-0.1	0.5	N.A.	
14-Apr	NMMA-12-1	0417-01	-0.2	0.4	3.2	N.A.	0.0	0.1	0.5	1.3	N.A.
18-Apr	NMMA-12-2	0418-02	0.0	-0.4	-1.0	N.A.	0.0	0.2	0.4	0.8	N.A.

response to propane. The response factors, determined for the outlet THC analyzer only, are listed in Table 4-4. The variation in instrument response factors serves as a measure of the day to day precision of the measurements as well as a correlation to styrene concentrations. The average relative response factor determined as the average of the daily average relative response factors for seven days of measurements, including values determined for all styrene calibration standards brought on site, is 2.40, with a standard deviation of 0.053 (±2.2 percent). The issue of daily variation in response factors was not addressed in the QAPP and no criterion for data acceptance has been suggested. The standard deviation of the response factors is within the precision requirement for the THC calibration and drift criteria.

Table 4-4
Specific Compound Relative Response Factors
for the Total Hydrocarbon Analyzer[a]

Date	Styrene Concentration (ppmv)	THC Response (ppmv)	Relative Response Factor	MMA Concentration (ppmv)	THC Response (ppmv)	Relative Response Factor
1-Apr	204	487.7	2.39			
3-Apr				45.6	62.7	1.38
7-Apr	204	506.8	2.48			
9-Apr	122	300.1	2.46			
9-Apr	204	490.3	2.40			
12-Apr	204	468.5	2.30			
12-Apr	59.2	148.4	2.51			
15-Apr	59.2	138.5	2.34			
16-Apr	59.2	137.6	2.32			
19-Apr	59.2	141.5	2.39	139.6	166.8	1.19
19-Apr	122	304.3	2.49			
Average			2.40			1.28

[a]Relative response factor is the THC instrument measurement divided by the calibration gas concentration, e.g., ppm propane/ppm styrene.

4.1.2   Organic Compound Concentrations (Method 18)

Method 18 calibrations were conducted every morning before starting a test run. Calibrations were checked after each run to ensure that the instrument remained in calibration for the test series. A measure of calibration is provided by the response factors (Figures 4-1 and 4-2), which are simply the calibration gas concentration divided by the area counts from the chromatogram (i.e., the GC response). As the figures indicate, there was more variability in the response factors early in the sampling program. This variability resulted from leaking of the gas injection valve during these early runs. On April 12, the valve was replaced, and the response factor variation was reduced (after Analysis No. 714).

Figure 4-1
Method 18 Response Factors for Styrene

Response Factors for Styrene - Method 18
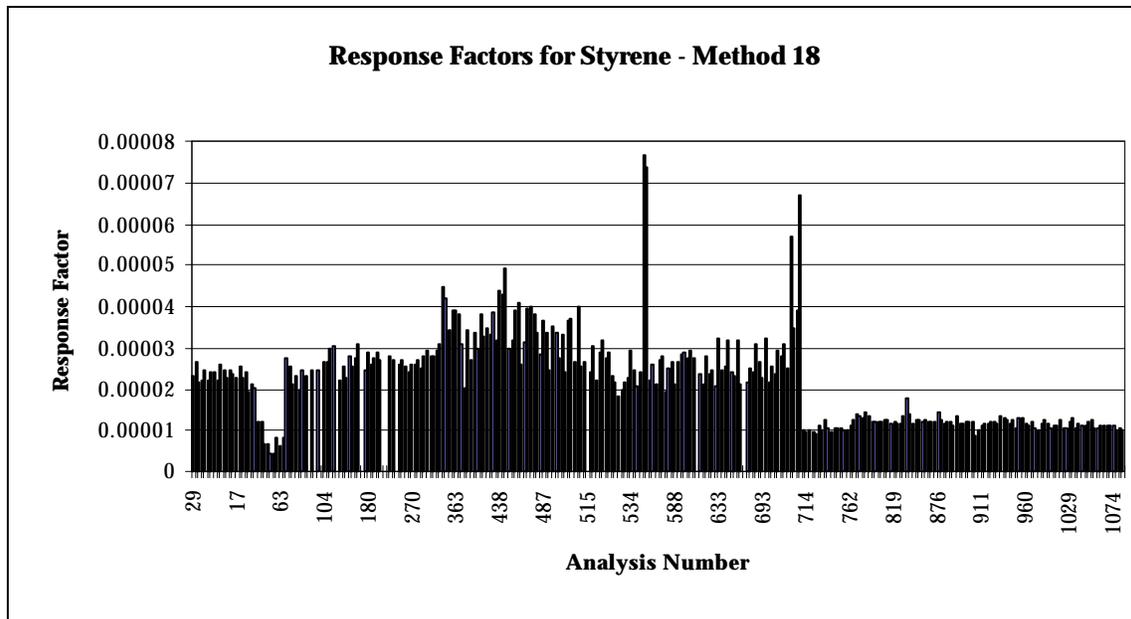
Method 18 data for this program have been used primarily to determine the relative quantities of styrene and MMA emitted during

gelcoating. The Method 18 results are also useful for comparison with the results of Method 25A testing. The relative concentrations of these two compounds in the TTE exhaust is important. An assessment of the ratio of the average response factors for styrene and MMA before and after April 12 (Analysis No. 712) shows that the leaking valve had little or no effect on the determination of the relative concentrations of these two compounds (Table 4-5) on average.

Figure 4-2
Method 18 Response Factors for Methyl Methacrylate
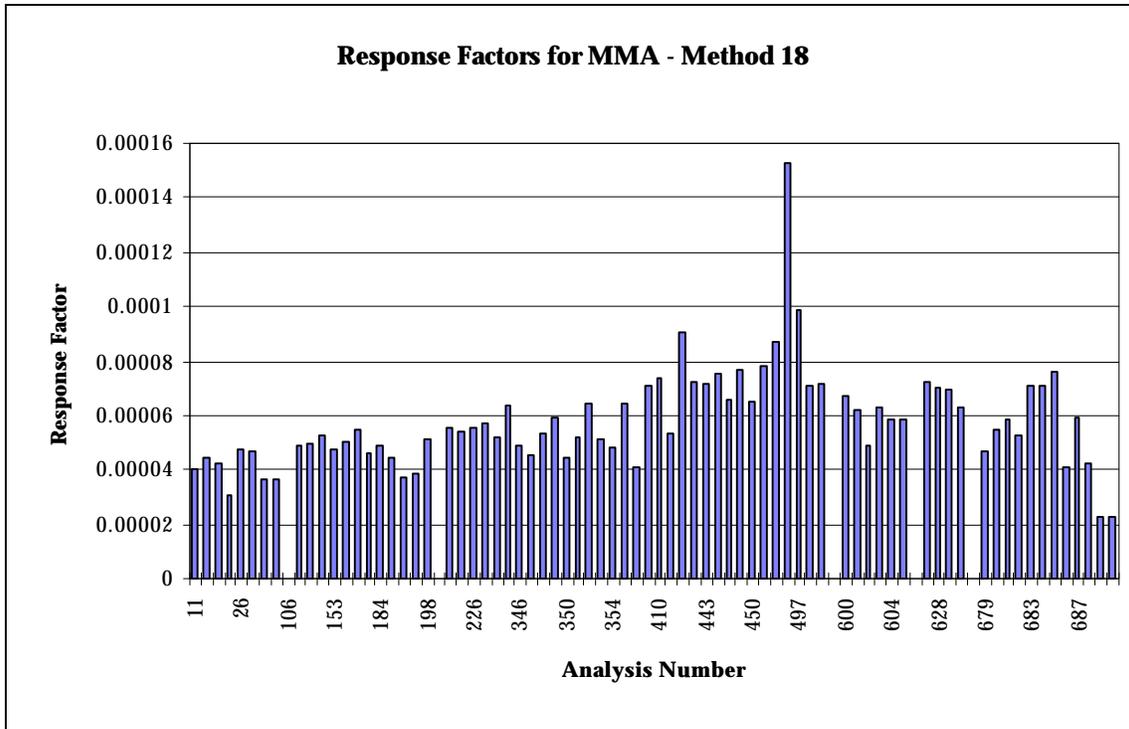
Table 4-5
Method 18 Response Factors for Target Compounds

	Before April 12	After April 12
Styrene	2.78E-05	1.17E-05
MMA	5.87E-05	2.27E-05
Styrene:MMA	0.473	0.516

Daily response factor ratios were also assessed (Figure 4-3). Only those days when styrene and MMA results were needed, and the final check conducted on April 19, are presented in the assessment. The figure illustrates the variability seen in the individual measurements, although the degree of variability is lessened through the averages. The ratio of the response factors (important in apportioning emissions to styrene and MMA for gelcoating test runs) was relatively constant for all gelcoat test days except April 3 and April 8. The results for April 3 appear to be consistent with other days; so the difference in response factor ratio did not appear to affect results for that test. The results from April 8, however, indicate much lower concentrations of MMA than noted for all other gelcoat test runs. Styrene results for that test run were consistent with other measurements and Method 25A results were typical. The abnormally low reading for MMA is attributed to poor response for that calibration.

Figure 4-3
Method 18 Response Factors for Selected Test Days
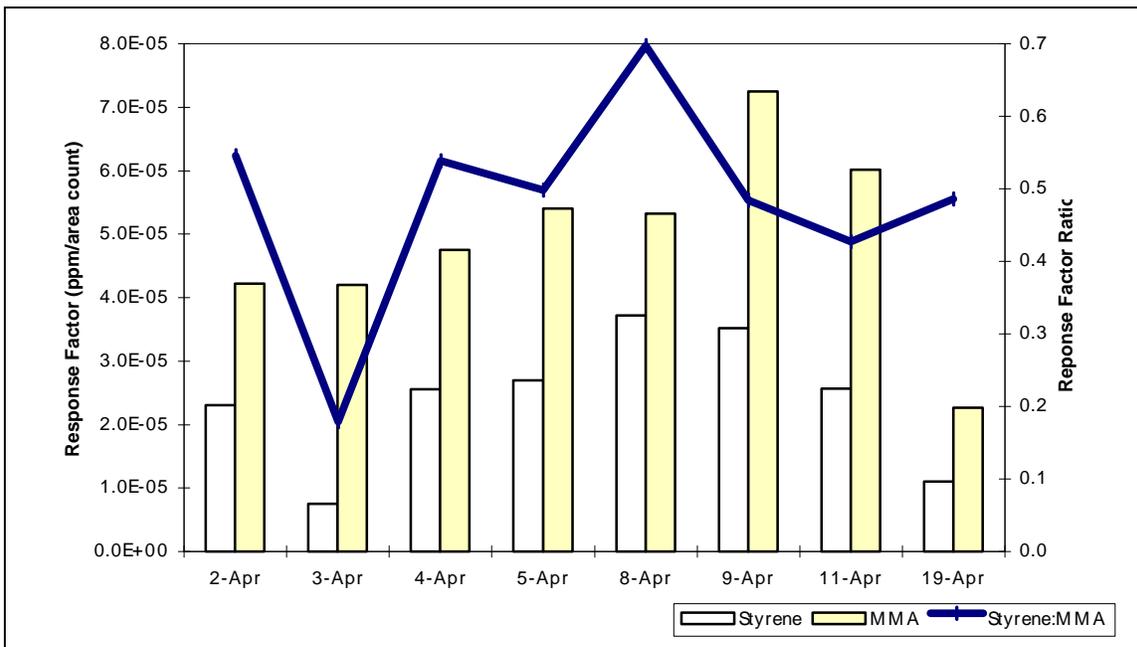
The relative concentrations of styrene and MMA were determined using the following approach. Area counts based on chromatographic analyses were determined for each compound at varying levels of gas concentrations. An average response factor was then determined for various gas standards. A point to point calibration curve was generated plotting area count against gas concentration assuming a linear function from point to point. These calibration curves (Appendix C) were then used to determine the relative concentrations of styrene and MMA in each sample analyzed.

Table 4-6 lists the QC measurements and their results. These measurements pertain only to styrene calibrations, because all gelcoating runs (i.e., the only runs involving MMA) had been completed by the time of equipment repair (April 12). All the pretest measurements of precision met the criteria defined for this program (within 10 percent of mean value). Drift exceeded the acceptance criteria of less than 5 percent of pretest values on four days; all these events occurred at the 59.2 ppmv styrene level. Data comparisons made between GC and THC concentration measurements show a higher level of styrene measured by the GC than by the THC analyzer, largely because the THC results are average results and the GC reports the concentration of a grab sample, generally selected by the GC operator to analyze temporal peaks in concentration. Because the reported emissions were calculated from the Method 25A results, drift in Method 18 measurements has no effect on the reported emissions.

Table 4-6
Gas Chromatography Calibrations (after April 12)

Date	Analysis No.	Concn (ppmv)	Area Count	RF	Precision (%Mean)	Drift	Comment
12-Apr	713	59.2	5971597	9.91E-06			Pre 5-2
	714	59.2	6009331	9.85E-06	-0.31		Pre 5-2
12-Apr	729	59.2	5958909	9.93E-06			Post 5-2
	730	59.2	6291424	9.41E-06			Post 5-2
	731	59.2	6429882	9.21E-06	-1.09		Post 5-2
	732	122	10977608	1.11E-05			Post 5-2
	733	122	11537000	1.06E-05	-2.48		Post 5-2
	734	204	16097608	1.27E-05			Post 5-2
	735	204	14421208	1.41E-05			Post 5-2
	736	204	21264480	9.59E-06			Post 5-2
	737	204	19247328	1.06E-05			Post 5-2
	738	204	19026992	1.07E-05	0.58		Post 5-2
12-Apr	759	59.2	5525818	1.07E-05			Post 2-1
	760	59.2	5794490	1.02E-05	-2.37		Post 2-1
	761	122	11881808	1.03E-05			Post 2-1
	762	122	10850096	1.12E-05	4.54		Post 2-1
14-Apr	768	0	352953				pre 5-2
	769	0	203009				pre 5-2
	470	59.2	4755664	1.24E-05			pre 5-2
	471	59.2	4167498	1.42E-05			pre 5-2
	472	59.2	4384538	1.35E-05	-2.54		pre 5-2
	473	122	9803558	1.24E-05			pre 5-2
	474	122	8547834	1.43E-05			pre 5-2
	475	122	8905798	1.37E-05	-2.05		pre 5-2
	476	204	16823296	1.21E-05			pre 5-2
	477	204	16883072	1.21E-05			pre 5-2
	478	204	17030400	1.20E-05	-0.43		pre 5-2
14-Apr	796	204	17182512	1.19E-05			post 5-2
	797	204	16327544	1.25E-05			post 5-2
	798	204	16258032	1.25E-05		3.18	post 5-2
14-Apr	818	204	17429680	1.17E-05			post 2-2
	819	204	16991360	1.20E-05		-0.59	post 2-2
	820	59.2	5021901	1.18E-05			post 2-2
	821	59.2	5041053	1.17E-05		-15.07	post 2-2
	823	0	0				
	824	0	0				
15-Apr	826	0	176395	0.00E+00			pre 16-1
	827	0	213703	0.00E+00			pre 16-1
	830	59.2	4179248	1.42E-05			pre 16-1
	831	59.2	5030979	1.18E-05	-9.25		pre 16-1
	832	122	9615066	1.27E-05			pre 16-1
	833	122	9712975	1.26E-05	-0.51		pre 16-1
	834	204	17192032	1.19E-05			pre 16-1
	835	204	16329160	1.25E-05	2.57		pre 16-1
	854	204	17244432	1.18E-05		-2.87	post 16-1
	855	59.2	4923560	1.20E-05		-7.27	post 16-1
	875	59.2	4928013	1.20E-05			post 15-1
	876	59.2	4053978	1.46E-05		0.54	post 15-1
	877	59.2	4739386	1.25E-05			post 15-1
	878	204	17330048	1.18E-05		-3.35	post 15-1

Table 4-6 (continued)

Date	Analysis No.	Concn (ppmv)	Area Count	RF	Precision (%Mean)	Drift	Comment
16-Apr	879	0	0				pre 16-2
	880	0	0				pre 16-2
	881	59.2	4915139	1.20E-05			pre 16-2
	882	59.2	4863680	1.22E-05	0.53		pre 16-2
	883	122	10776440	1.13E-05			pre 16-2
	884	122	9171008	1.33E-05			pre 16-2
	885	122	10341320	1.18E-05			pre 16-2
	886	122	10572206	1.15E-05	-1.10		pre 16-2
16-Apr	905	59.2	4956816	1.19E-05			post 16-2
	906	59.2	4863680	1.22E-05		-0.42	post 16-2
	910	0	660	0.00E+00			post 16-2
	911	122	11027728	1.11E-05			post 16-2
	912	122	10367112	1.18E-05		-2.17	post 16-2
16-Apr	934	0	0				post 15-2
	935	122	10505456	1.16E-05			post 15-2
	936	122	10076096	1.21E-05		1.64	post 15-2
	937	59.2	4985315	1.19E-05			post 15-2
	938	59.2	5178906	1.14E-05		-3.76	post 15-2
17-Apr	939	0	0				pre 12-1
	940	0	2044				pre 12-1
	941	59.2	4324157	1.37E-05			pre 12-1
	942	59.2	4535176	1.31E-05			pre 12-1
	943	59.2	4768189	1.24E-05	-2.50		pre 12-1
	944	122	10597432	1.15E-05			pre 12-1
	945	122	9772608	1.25E-05	4.05		pre 12-1
17-Apr	960	204	17712032	1.15E-05			post 12-2
	961	204	18269232	1.12E-05	-1.55		post 12-2
	962	122	10231520	1.19E-05		-0.62	post 12-2
	963	59.2	5499240	1.08E-05			post 12-2
	964	59.2	5894784	1.00E-05		-18.30	post 12-2
18-Apr	978	0	1915				pre 9-1c
	979	0	3089				pre 9-1c
	980	59.2	5035434	1.18E-05			pre 9-1c
	982	59.2	5181651	1.14E-05	-1.43		pre 9-1c
	983	204	19345344	1.05E-05			pre 9-1c
	984	204	18797024	1.09E-05	1.44		pre 9-1c
18-Apr	1018	204	18110944	1.13E-05			post 9-1
	1020	204	19007808	1.07E-05		2.80	post 9-1
	1021	59.2	5687642	1.04E-05		-10.20	post 9-1
19-Apr	1035	59.2	4908355	1.21E-05			pre 9-2
	1036	59.2	4736861	1.25E-05	1.78		pre 9-2
	1037	204	18883424	1.08E-05			pre 9-2
	1038	204	19033904	1.07E-05	-0.40		pre 9-2
19-Apr	1070	204	18327536	1.11E-05			post 9-2
	1071	204	18467392	1.10E-05		3.05	post 9-2
	1072	122	11046080	1.10E-05			post 9-2
	1073	122	10864040	1.12E-05			post 9-2
	1074	122	11025512	1.11E-05		3.28	post 9-2
	1075	59.2	5985747	9.89E-06			post 9-2
	1076	59.2	5700285	1.04E-05	0.00	-17.44	post 9-2
19-Apr	1077	59.2	5780963	1.02E-05	0.01		Bias test
19-Apr	1078		6178867				MMA Bag 7
	1079		6176253				MMA Bag 7

### 4.1.3 Comparison of Methods in Determining Emissions

There is relatively good agreement between the results of the two methods, with most of the measurements within 6-8 percent. The runs that had more divergent results were typically those involving smaller molds. Table 4-7 presents a comparison of the results in terms of percent of available volatile material, which for most of the testing was styrene only.

Table 4-7
Comparison of Emission Results by Two Methods

Date	Test	Description	Emissions (% Available) - Method 25A	Emissions (% Available) - Method 18
2-Apr	NMMA-6-P	18 Deck Gel	47.0%	54.1%
4-Apr	NMMA-7-1	28 Hull 35 R	15.7%	18.2%
7-Apr	NMMA-7-2	28 Hull 35 R	18.8%	18.4%
8-Apr	NMMA-6-1	18 Deck Gel	42.3%	43.1%
8-Apr	NMMA-3-2	18 Hull Gel	54.2%	53.5%
8-Apr	NMMA-4-2	18 Deck 35 R	16.1%	16.1%
9-Apr	NMMA-1-2	18 Hull 35R	13.9%	13.2%
9-Apr	NMMA-11-1G	CFA Gel	43.4%	39.0%
9-Apr	NMMA-11-1R	CFA 35R	29.8%	37.1%
10-Apr	NMMA-14-1	18 Deck 35R - FC	11.1%	10.4%
10-Apr	NMMA-13-1	18 Hull 35R - FC	10.5%	11.0%
10-Apr	NMMA-11-2R	CFA 35R	28.8%	26.8%
11-Apr	NMMA-6-2	18 Deck Gel	45.2%	46.4%
11-Apr	NMMA-14-2	18 Deck 35R - FC	12.1%	11.1%
11-Apr	NMMA-13-2	18 Hull 35R - FC	10.5%	10.9%
12-Apr	NMMA-11-3R	CFA 35R	52.0%	44.8%
12-Apr	NMMA-5-1	18 Deck 42R	20.4%	14.1%
12-Apr	NMMA-2-1	18 Hull 42R	22.3%	24.1%
14-Apr	NMMA-5-2	18 Deck 42R	20.8%	22.4%
14-Apr	NMMA-2-2	18 Hull 42R	18.2%	14.2%
15-Apr	NMMA-16-1	18 Deck 42R-FC	12.2%	12.0%
15-Apr	NMMA-15-1	18 Hull 42R-FC	11.6%	11.7%
16-Apr	NMMA-16-2	18 Deck 42R-FC	14.0%	14.4%
16-Apr	NMMA-15-2	18 Hull 42R-FC	10.6%	10.8%
17-Apr	NMMA-12-1	CFA 42R	54.6%	44.8%
18-Apr	NMMA-9-1	28 Hull 42R	22.8%	25.5%
19-Apr	NMMA-9-2	28 Hull 42R	23.0%	23.5%
18-Apr	NMMA-12-2	CFA 42R	39.2%	38.2%

Certainly, the concentration measurements made using both approaches yielded consistent results. The THC concentration trace for Run NMMA-7-1 and an equivalent THC concentration trace generated using measured styrene and MMA concentrations and the response factors developed during this program (2.40 for styrene and 1.39 for MMA), although not identical, show fair agreement for the different FIDs (Figure 4-4).

**Figure 4-4
Comparison of Total Hydrocarbon Traces by Two Methods**
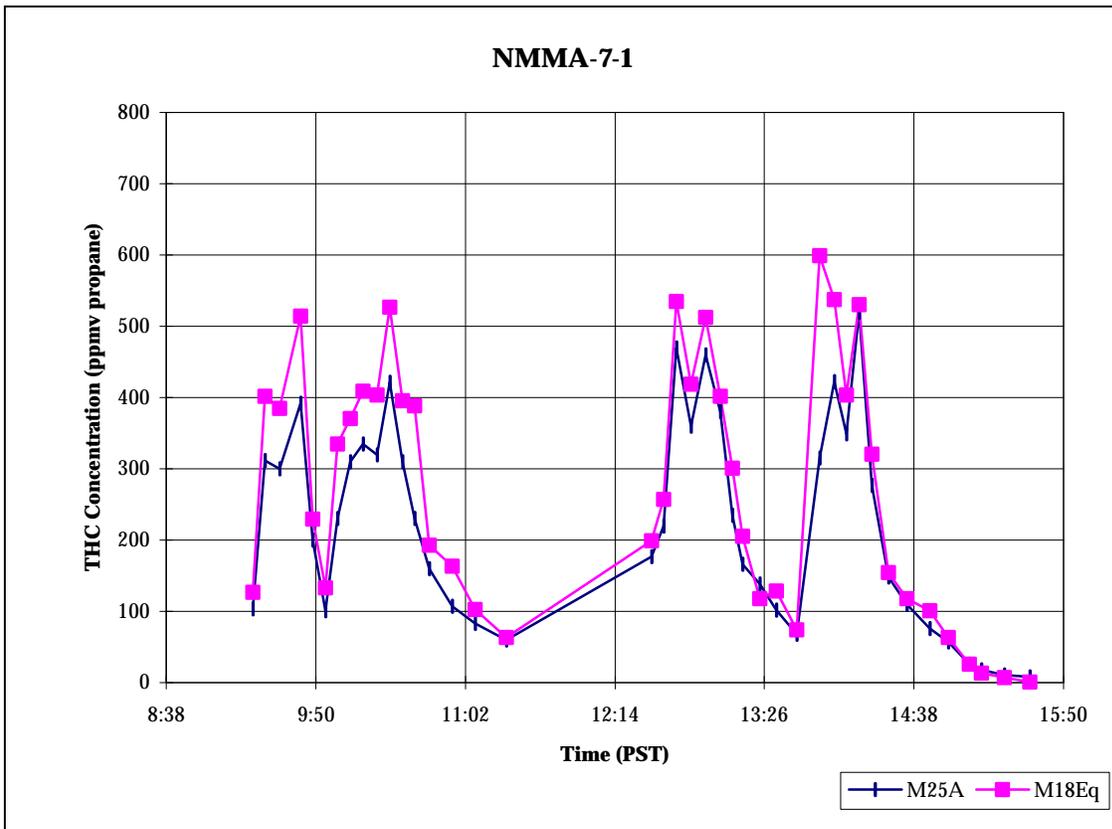
4.2   Gelcoat and Resin Flow Rate

Spray gun resin and gelcoat flow rates were determined at the start and end of each test day (Table 4-8). A single assessment was made during each flow rate check. Resin-to-glass ratios were assessed during the initial resin calibrations (Table 4-8). Catalyst-to-resin/gelcoat ratios were set according to the catalyst pump stroke rate. These ratios remained constant during testing.

Table 4-8
Spray Equipment Data Summary

Equipment	Date	Flow Rate (g/min) Pre test	Post test	Percent Change	Resin (g)	Glass (g)	Percent Glass
Spray gun/ Resin	3-Apr				327	180	35.5
	4-Apr				324	128	28.3
	5-Apr	2888	2916	1.0	148	77	34.2
	7-Apr	2828	3092	9.3	277	149	35.0
	8-Apr	2792	2896	3.7	301	176	36.9
	9-Apr	2836	2776	-2.1	242	127	34.4
	10-Apr	2956	2784	-5.8	222	114	33.9
	12-Apr	2892	3100	7.2	218	117	34.9
	14-Apr	3192	3096	-3.0	378	201	34.7
	17-Apr	3100			317	152	32.4
	18-Apr	2944	2992	1.6	300	160	34.8
	19-Apr	3036	2904	-4.3	256	148	36.6
Flow Chopper	10-Apr	2956	2784	-5.8	222	114	33.9
	11-Apr	2556	2668	4.4	297	158	34.7
	15-Apr	3164	3388	7.1	406	192	32.1
	16-Apr	3084	3072	-0.4	317	162	33.8
Spray gun/ Gelcoat	3-Apr	1264	1256	-0.6			
	4-Apr	1256	1260	0.3			
	5-Apr	1264	1264	0.0			
	8-Apr	1260	1268	0.6			
	9-Apr	1272	1276	0.3			
	11-Apr	1256	1260	0.3			

4.3   <u>**Air Velocity over Mold Surface**</u>

Air flow over the mold surface was assessed twice during the test program. These measurements reflect a best assessment approach and no presumption of accuracy has been made. In addition to being difficult to assess accurately, air flow over the mold (i.e., velocity) was dependent on mold position in the TTE, a factor that changed every time a tool was brought into the enclosure or moved within the enclosure in the process of lamination or gelcoating. The velocities measured at the mold surface were consistent with measurements made over mold surfaces in the manufacturing area, taking into account that the TTE was designed for induced draft flow. Greater emphasis was placed on controlling air flow through the enclosure to reflect conditions found in the facility than on attempting to duplicate the velocities measured during previous studies using parts not typical of boat building.

Measurements made during a technical system audit performed by MRI and the EPA were consistent with the measurements made during this program. Their findings are reported in MRI's *Technical Systems Audit of a Laboratory Spray Booth at the U.S. Marine Facility in Arlington, Washington* (May 29, 1997).

4.4   <u>**Exhaust Flow Rate**</u>

Air flow rate through the enclosure was measured and monitored as described in Section 3.2.2. Accuracy of the velocity measurement can be assessed by observing the variability of the velocity head measurements (which were accurate to within 0.005 inches of water) during the test. This yields an assessment in terms of percent which can be compared with the acceptable criteria of the method. Variability measurements for all test runs are shown with

the test averages (Table 4-9). The overall average variability in flow rate for the program was 2.9 percent, and no measure for an entire day was greater than 6.9 percent. The two instances of greatest variability were affected by the two measurements on April 4, early in the program, when TTE exhaust filters had been allowed to become partially blocked and were first being changed during the test runs.

Table 4-9
Variability Measures for Flow Rate During Test Runs

Date	Flow Rate Variability (%)			Average
	Run1	Run 2	Run 3	
2-Apr	1.0			1.0
3-Apr	2.5	3.2		2.9
4-Apr	4.9	8.9		6.9
5-Apr	2.2	1.2		1.7
7-Apr	2.5			2.5
8-Apr	1.4	3.3	1.8	2.2
9-Apr	3.2	3.5	0.9	2.6
10-Apr	2.3	2.8	3.0	2.7
11-Apr	2.9	4.5	3.7	3.7
12-Apr	4.3	4.2	3.7	4.1
14-Apr	3.2	2.4		2.8
15-Apr	3.3	3.5		3.4
16-Apr	2.1	1.7		1.9
17-Apr	2.5			2.5
18-Apr	2.7	2.4		2.5
19-Apr	2.3			2.3
Average				2.9

Flow rates during the test program were observed (based on the continuous, fixed point velocity head measurements) to vary based on filter collection and other operations. The exhaust plena on both longitudinal sides of the enclosure were equipped with filter media (spun fiberglass air filters). Flow rate decreased with time as these filters collected air-borne resin containing reactive styrene and MMA, which polymerized on the filter media. Periodically, these filters were replaced to ensure more consistent flow rates through the

enclosure for all test runs. The build-up of material on the filters was one cause of the variability in flow rate measured during the overall program. To some smaller extent, this affected flow rate over the course of the test run, more so for the larger articles which required more resin. A second cause of the fluctuation in flow rate was activity in the building where the enclosure was located. Temperature was affected by the opening and closing of doors into the building. Changes in the system operated by RTI also had some effect on the measurement of flow because both systems were connected to the same exhaust system at the U.S. Marine facility. Changes made to accommodate their operation had some effect on exhaust system pressure, thus affecting flow rate through the larger enclosure.

4.5 Exhaust Air Temperature

As described in Section 3.2.3, enclosure air temperature was monitored continuously using a type K thermocouple at the location of the fixed pitot and the DAS, calibrated at two points. The accuracy of this measurement was 0.005°F (or 0.0001 mV). Measurements of precision were not made during the test program; however, literature suggests the precision of type K thermocouples, assessed in a laboratory environment, will yield a precision of 0.5°F, or within 1 percent of the measured values.

4.6 Resin/Gelcoat Balance

Balance calibration checks were often performed with barrels of resin still on the platform and always performed without zeroing the balance. Therefore, the calibration error was calculated in terms of percent of weight change rather than the displayed weight value (Table 4-10). All calibration results display a level of accuracy, measured as percent error, meeting the

criteria of the QAPP (within 2 lb). Based on the maximum error measure of 0.2 percent and the high end of the scale measurements (i.e., 500 lb), the accuracy was within approximately 1 lb.

Table 4-10
Results of Balance Calibration Checks

Date	Tare Weight (lb)	Initial Scale Reading (lb)	Scale Response (lb)	Change in Weight (lb)	Error (% Tare)
6-Apr	0	0.0	0	0.0	NA
	500	0.0	500.1	500.1	0.02
	300	0.0	300.1	300.1	0.03
	100	0.0	100.1	100.1	0.10
8-Apr	0	0.0	-1.9	0.0	NA
	100	0.0	98.1	100.0	0.00
	200	0.0	197.9	199.8	-0.10
	300	0.0	297.8	299.7	-0.10
	400	0.0	397.6	399.5	-0.12
	500	0.0	497.5	499.4	-0.12
10-Apr	0	201.7	201.7	0.0	NA
	50	201.7	251.7	50.0	0.00
	100	201.7	301.7	100.0	0.00
	200	201.7	401.7	200.0	0.00
15-Apr	0	231.7	231.7	0.0	NA
	100	231.7	331.7	100.0	0.00
	200	231.7	431.9	200.2	0.10
	250	231.7	481.8	250.1	0.04
19-Apr	0	0.0	-1.33	0.0	NA
	100	0.0	98.5	99.8	-0.17
	200	0.0	198.7	200.0	0.02
	300	0.0	298.7	300.0	0.01
	400	0.0	398.8	400.1	0.03
	500	0.0	498.7	500.0	0.01
	100	0.0	98.9	100.2	0.23

4.7 Technical Systems Audit

The performance of the sampling system was assessed through an audit and styrene recovery tests. Audits of the THC sampling, balance, and flow measurement systems were performed. The system audit was conducted by

EPA/OAQPS and its contractor MRI. The EPA/OAQPS audit will report on this project, but the final report has not been released. Also, styrene recovery tests (styrene evaporation tests) were performed in accordance with the QAPP.

4.7.1 Total Hydrocarbon Measurement

The results of the Method 25A system audit are presented in Table 4-11. The audit gas was introduced in two manners during the performance of the audit. One method involved filling a Tedlar® bag with the audit gas and attaching it to the sampling probe. In the second method, the audit cylinder was connected to the calibration system and the gas was introduced to the sampling system in the same manner as all on-site calibrations were performed; the propane audit was performed only with this latter method. Both methods yield results representative of the system performance.

Table 4-11
Audit Results for Method 25A Measurements

Date	Analyzer Measurement (ppmv C_3H_8)	Result (ppmv as styrene)	Gas Standard (ppmv)	Compound	Result (%)	Notes
15-Apr	84.3	36.8	39.7[a]	Styrene	-7.3	b, c
16-Apr	85.3	36.8	39.7	Styrene	-7.3	b, d
	1000		999	Propane	+0.1	d

a. Gas standard reported at 41.7 ppmv; on site analysis by GC reported 39.7 ppmv.
b. Response factor to styrene is 2.289 on 4/15 and 2.318 on 4/16.
c. Test performed with audit gas in Tedlar® bag.
d. Test performed with audit gas in vented cylinder.

Conversion of THC concentration to equivalent concentrations of styrene was done using daily relative response factors determined from the THC analyzer (Method 25A) on the day of the audit. Using the pre-test analysis by Scott Specialty Gases (41.7 ppmv styrene), the analysis by THC analyzer was about 12 percent low. However, on-site analysis of the standard by GC indicated

that the concentration in the audit sample was only 39.7 ppmv. Although this assessment does not meet the requirements of a protocol gas certification, the results indicate that the certified value of the audit cylinder may be slightly low. Comparing to concentration from this reanalysis of the standard shows that the THC analysis was only 7.3 percent low, within the criterion established for the program. This low recovery does not appear to be a system malfunction. The good results of the propane audit indicate the low results of the styrene audit sample are not a result of sampling system bias (leaks). Further, procedures in determining response factors included introduction of the gas at the probe, thus incorporating any system characteristics into the results. The results of the styrene audit indicate the sampling system, as used in the performance of the audit, results in an under reporting of styrene concentrations by less than 10 percent at a 40-ppmv concentration, or about 3 ppmv styrene.

4.7.2   Weigh Cell Balance

The results of the weigh cell balance audit performed on April 16 indicate that greater than 5 percent error results when weighing less than 3000 g, or approximately 6.6 lb, on an empty scale (Table 4-12). However, testing was conducted with a drum of resin or gelcoat or resin in place, meaning that the scale was used during the test program in its normal operating range. The results of the audit and the calibration checks (Table 4-10) demonstrate that even small weight changes can be measured accurately through the weight range experienced during this test program. Although the audit was conducted with an empty balance, the calibration checks were conducted with both empty and loaded scale (i.e., with a drum of resin in place). Data collected from the calibration check using certified weights on April 8 indicate that a less than 1 lb change in weight at an elevated balance response (512 lb) was accurately quantified. These data indicate the balance was capable of accurately measuring

500-g (1.1-lb) changes in weight in the range of operation, well within specifications of the QAPP (i.e., 2 lb). Two data points from the audit can be used to assess the precision of the weight measurements. The replicate weighing performed at 57 and 157 lb indicate a precision of greater than 0.2 lb, also within QAPP specifications.

Table 4-12
Results of Audit on Balance

Date	Audit Weight (g)	Scale Response (lb)	Scale Initial (lb)	Net Scale Response (lb)	Difference (lb)	% Error
8-Apr[a]	3000	504.3	497.6	6.7	0.086	1.30
	5000	508.7	497.6	11.1	0.077	0.70
	6000	510.9	497.6	13.3	0.072	0.55
	6500	512	497.6	14.4	0.070	0.49

Date	Audit Weight (lb)	Scale Response (lb)	Scale Initial (lb)	Net Scale Response (lb)	Difference (lb)	% Error
16-Apr[b]	0	-1.92	-1.92	0	0.00	NA
	0.002	-1.94	-1.92	-0.02	-0.022	-1007.18
	0.01	-1.96	-1.92	-0.04	-0.053	-402.39
	0.04	-1.99	-1.92	-0.07	-0.105	-298.45
	0.1	-1.86	-1.92	0.06	-0.086	-58.76
	0.4	-1.65	-1.92	0.27	-0.096	-26.22
	2.6	0.55	-1.92	2.47	-0.101	-3.91
	7	5.06	-1.92	6.98	0.000	0.00
	57	54.9	-1.92	56.82	-0.180	-0.32
	157	154.74	-1.92	156.66	-0.340	-0.22
	457	454.9	-1.92	456.82	-0.180	-0.04
	357	355	-1.92	356.92	-0.080	-0.02
	157	154.9	-1.92	156.82	-0.180	-0.11
	57	55	-1.92	56.92	-0.080	-0.14
	7	5	-1.92	6.92	-0.060	-0.86
	2.6	0.5	-1.92	2.42	-0.15	-5.86

[a]Calibration check using certified weights.
[b]Audit using certified weights.

4.7.3   Flow Measurement

The results of the flow rate audits were reported in the draft audit report. Comparison of the audit results to the measurements made for the test runs of the same days indicate good agreement for velocities and flow rates measured using Method 2 (Table 4-13). The preliminary velocity measurement by hot wire anemometer made by the auditor on April 14 indicated a greater velocity than calculated from pitot tube measurements. The differences are attributed to the hot wire anemometer velocity being a point measurement compared with an average velocity resulting from the pitot tube measurements and the presence of hydrocarbon in the stream, which can cause hot wire anemometer velocity readings greater than actual velocities.

Table 4-13
Results of Flow Rate Audit

Date	Test	Velocity (ft/min)	Flow Rate (cfm)
14-Apr	Audit-hot wire	1930	
	NMMA-5-2	1738	3071
	NMMA-2-2	1728	3053
15-Apr	Audit-pitot	1787	3157
	NMMA-16-1	1866	3297
	NMMA-15-1	1793	3168

4.7.4   Styrene Evaporation Test

In accordance with the QAPP, styrene evaporation tests (the towel tests) were conducted to evaluate the capture and recovery of styrene by the sampling system. Two tests were completed, one at the initiation of the testing program and one at the conclusion of the program. In both cases, the recovered quantity of styrene met the acceptance criteria for a good system (±10 percent) (Table 4-14).

Table 4-14
Results of Styrene Evaporation Tests

	Towel-1	Towel-2
Date	4/1/97	4/19/97
Material Losses (g)	1199	1095
Temperature (°F)	65.6	66
Flow rate (acfm)	3017	3306
Average THC Concentration (ppmv)	117.8	116.7
Duration (min)	66	59
Measured Emissions (g)	1202	1165
Percent Difference	0.21	6.4

The first test represents the best measure of the system and its operation because no testing had been conducted in the building and, therefore, no background styrene in building air or booth air interfered with the results. The results from the first test showed excellent agreement between the measured quantity of styrene evaporated from the apparatus (provided by RTI) and the emissions determined by measuring stack gas concentrations and flow rate. The closure between these two measurements is not as close for the final test, however. Although it is true that the flow rate through the enclosure was greater during the second test, the greater emissions measured are attributed more to the mold left in the enclosure after previous lamination testing. Although the measured styrene concentrations were adjusted for the concentration in the incoming air and attempts were made to account for the background concentration in the enclosure, it is likely that some of the styrene included in the measured emissions may have been generated by the mold and part left in the enclosure (i.e., residual curing emissions).