# IN-DEPTH SURVEY REPORT
# EVALUATION OF SPRAY GUN TECHNOLOGY FOR OCCUPATIONAL EXPOSURE TO AUTO PAINT SHOP HAZARDS

AT

DeVilbiss Automotive Refinishing Products
Maumee, Ohio 43537

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| PLANT SURVEYED | DeVilbiss Company<br>1724 Indian Wood Circle<br>Maumee, Ohio 43537 |
| SIC CODE | 3563 |
| SURVEY DATE | September 14-19, 1992<br>July 6-8, 1993 |
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ABSTRACT

Autobody repair shops generally use either conventional or High Volume-Low Pressure (HVLP) spray-painting guns to paint repaired cars In conventional spray-painting guns, compressed air is accelerated through a nozzle where a reduction in static pressure causes the paint to flow from a cup into an orifice where the atomization occurs The pressure at the cap that contains this orifice is typically 50-65 psig In HVLP spray-painting guns, this pressure is less than 10 psig, which reportedly results in a more efficient transfer of the paint from the gun to the surface being painted If this is true, substituting an HVLP spray-painting gun for a conventional spray-painting gun should reduce particulate paint overspray concentrations in the spray-painting booths The effect of spray-painting gun choice, HVLP or conventional, upon solvent and particulate overspray concentrations was experimentally studied in a downdraft spray-painting booth This experiment was conducted by repeatedly applying two coats of paint to a car body shell, a 1993 Pontiac Grand Am, which was coated with a polyethylene film This experiment involved two spray-painting guns and two tints of a white paint The two spray-painting guns were a gravity-feed conventional spray-painting gun and a gravity-feed HVLP spray-painting gun During each experimental run, particulate overspray concentrations, solvent concentrations, film thickness on the autobody, and mass of paint were measured The film thickness per mass of paint for the HVLP gun was 33 percent higher than what was observed for the conventional spray-painting gun This difference was statistically significant (Prob >F = 0 0015) Apparently, the HVLP spray-painting gun had a much higher transfer efficiency than the conventional spray-painting gun The conventional spray-painting gun was associated with particulate overspray concentration per unit of film thickness that were a factor of 2 higher than with the HVLP gun Again, this difference was statistically significant (prob > F = 0 0009) However, the HLVP spray-painting gun reduced the solvent concentrations by 21 percent which was not statistically significant

## INTRODUCTION

During autobody repainting operations, spray-painting guns are used which can be classified as either conventional or High Volume-Low Pressure (HVLP) guns In conventional spray painting guns, compressed air is accelerated through a nozzle where a reduction in static pressure occurs The reduced static pressure causes the paint to flow from a cup into an orifice where the atomization occurs When this cup is below the atomization nozzle, air pressure at the gun cap is 65 psig These guns are termed "suction" or "siphon cup" spray painting guns When this cup is above the atomization nozzle, the flow of paint is augmented by gravity and such guns are commonly called "gravity-feed" spray painting guns In HVLP spray painting guns, paint is atomized with air pressures at this orifice of less than 10 psig In some HVLP guns, the cup is above the atomization nozzle and gravity assists the flow of the paint into the atomization orifice In other cases, the cup is below the atomization nozzle and a controlled air pressure is used to meter the flow of paint into the orifice where atomization occurs

Reportedly, HVLP spray painting guns are much more efficient at transferring the paint from the gun to the car than conventional spray painting guns HVLP guns are believed to have a transfer efficiency of at least 65 percent, and conventional spray painting guns are commonly reported to have a transfer efficiency of 20-40 percent [1,2,3] As a result, some air pollution control districts require the use of spray painting equipment with a transfer efficiency of at least 65 percent [4] If HVLP spray painting guns actually have a transfer efficiency of 65 percent, most of the paint becomes a surface coating instead of a potentially harmful overspray Overspray is the paint mist which does not coat the surface being painted If conventional spray painting guns only have a transfer efficiency of 20-40 percent, most of the paint becomes an overspray which contaminates the air in the worker's breathing zone Furthermore, this lower transfer efficiency increases the amount of paint needed to obtain the same paint film thickness Thus, switching from a conventional to an HVLP spray painting gun should reduce worker exposure to paint overspray and the paint usage

Reducing worker exposure to paint overspray may minimize adverse health effects associated with painting The International Agency for Research on Cancer (IARC) has reviewed the health effects associated with painting operations [5] In the IARC publication, the term "painters" included workers who apply paint to surfaces during a variety of tasks including autobody refinishing After reviewing a wide range of publications, they concluded "There is sufficient evidence for the carcinogenicity of occupational exposure as a painter " In addition, they noted that painters suffer from allergic and non-allergic contact dermatitis, chronic bronchitis, asthma, and adverse central nervous system effects

Polyisocyanates, such as hexamethylene diisocyanate trimers, are used in autobody repainting operations to obtain a hard, durable surface Overexposure to polyisocyanates can cause skin, eye, nose, throat, and lung irritation, occupational asthma, and reduced lung function [6,7,8,9] In addition, workers can become sensitized, and any exposure can result in potentially life-threatening asthma [10] These health effects may result from a large single overexposure or from repeated overexposures at lower concentrations As a result of these health effects, a major producer of 1,6-hexamethylene diisocyanate (HDI) trimers has recommended a ceiling exposure of 1 $mg/m^3$, and this exposure limit has been adopted by Oregon Occupational Safety and Health Administration [11] By using spray painting equipment, which more efficiently transfers paint from the spray painting gun to the surface, worker air contaminant exposure and the risk of adverse health effects should be reduced

The regulatory and commercial literature indicates that substituting HVLP spray painting guns for conventional spray painting guns should reduce the paint overspray generation However, there is little scientific literature to indicate whether the claimed improvements in transfer efficiency actually occur One experimental study conducted in the wood finishing industry indicates that HVLP spray painting guns are not inherently more efficient than other types of spray painting guns [12] This suggests a need to evaluate whether HVLP spray painting guns can actually reduce worker exposure to paint overspray

## THEORETICAL ESTIMATE OF EFFECT OF TRANSFER EFFICIENCY ON OVERSPRAY CONCENTRATIONS

Transfer efficiency, $\eta$, can be defined as the fraction of paint solids which actually coats the surface being painted

$$\eta = \frac{m}{M} \tag{1}$$

where
- M = mass of paint solids used
- m = paint solids deposited on car

The ventilation rate, Q, the paint used, the transfer efficiency, and the time, t, required to do the painting can be used to compute the expected concentration, $C_p$, of paint solids in the air

$$C_p = \frac{M(1-\eta)}{Qt} \tag{2}$$

This equation assumes that the particulate overspray is being perfectly mixed in the dilution ventilation During a painting operation, a specified thickness or mass of paint must be put on the surface that is being painted In order to more clearly see the effect of transfer efficiency upon the particulate overspray concentration, M can replaced by $m/\eta$ to obtain this equation

$$C_p = \frac{m}{Qt} \left( \frac{1-\eta}{\eta} \right) \quad (3)$$

In a well-mixed room, all of the solvent evaporates and the relationship between solvent concentration, $C_s$, and paint application rate can be stated

$$C_s = \frac{m_s}{Qt\eta} \quad (4)$$

where

$m_s$= the mass of carrier solvent on the car

In order to clearly illustrate the effect of transfer efficiency upon worker air contaminant exposures, equations 3 and 4 can be rearranged to express the relationship between transfer efficiency and dimensionless particulate concentration ($C_{dp}$) and a dimensionless solvent concentration ($C_{ds}$)

$$C_{dp} = \frac{C_p Qt}{m} = \frac{(1-\eta)}{\eta} \quad (5)$$

$$C_{ds} = \frac{C_s Qt}{m_s} = \frac{1}{\eta} \quad (6)$$

In Figure 1, dimensionless particulate and solvent concentrations are plotted as a function of transfer efficiency  Increasing transfer efficiency from 0 4 to 0 65 reduces the particulate overspray concentrations by at least a factor of 2 8 and solvent concentrations exposure by a factor of 1 6

## EXPERIMENTAL PROCEDURES

The study's objective is to evaluate whether the type of spray painting gun significantly affects the concentration of these air contaminants in the spray painting booth  titanium, refined petroleum solvents, and particulate overspray (mass concentration of paint solids)  In addition, the effect of spray painting gun used upon film thickness and mass of paint used were evaluated

This experiment involved 16 experimental runs  During each run, the painter applied two coats of paint to a car body shell (Grand Am, Pontiac), simulating a complete paint job in an autobody shop  To allow the paint to be removed at the end of the test, the car body shell was coated with a polyethylene film For each run, air contaminant concentrations, mass of paint used, painting times, and paint film thicknesses were measured  For each experimental run, the painter switched between two tints of a white base coat (Chromabase, Dupont, Willmington, DE) so that there was enough of a contrast to see the freshly applied paint  At the start of the even-numbered runs, the painter switched between a conventional gravity-fed spray painting gun (Model GFG-504-

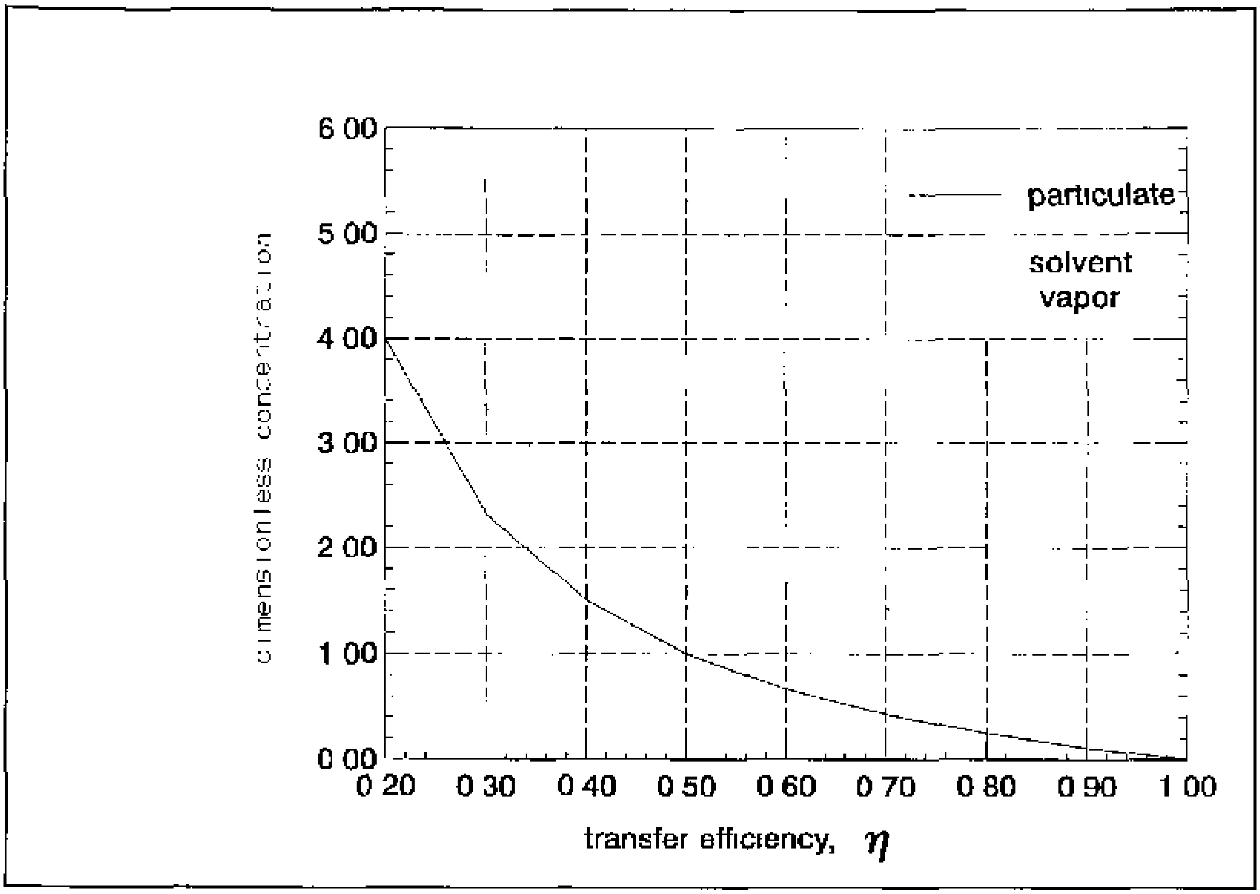



Figure 1 Effect of transfer efficiency upon particulate and vapor overspray concentrations assuming mixing in a spray painting booth

43-FF, DeVilbiss, Toledo, OH, and an HVLP, gravity-fed spray painting gun (Model GFHV-501-57-DFW) This was done so that each spray painting gun was used four times with each paint

AIR CONTAMINANT CONCENTRATION MONITORING

Particulate overspray concentrations were measured as total dust concentrations were measured using NIOSH Method 0500 [13] Samples were collected on preweighed PVC filters at a flow rate of 5 0 liters per minute using personal sampling pumps (Aircheck Sampler, Model 224 -- PCXR7, SKC Inc, Eighty Four, PA) The weight gain of the filter is used to compute the milligrams of particulate overspray per cubic meter of air After gravimetric analysis, the samples were placed in a 50 mL Teflon beakers and the filter substrate was removed by setting these beakers in a low temperature oxygen plasma asher for two hours at 200 watts The paint matrix was eliminated by wet ashing at 150 °C with 2 mL of a 4/1 mixture of concentrated nitric/perchloric acid and 1 mL of hydrofluoric acid at 150 °C After evaporation to dryness, the residues were dissolved in 1 mL of Spectrosol 'Zeolite Reagent A', 0 1 mL of concentrated nitric acid, and 5 mL of deionized water  Zeolite A is a mixture of hydrofluoric and hydrochloric acids  After appropriate dissolution time, the excess hydrogen fluoride was neutralized with 5 mL of Spectrosol 'Reagent B,' which is a proprietary solution of tertiary amines  The samples were brought to a final volume of 13 mL with deionized water  Then, the samples were analyzed for titanium by inductively coupled plasma-atomic emission spectroscopy  The limits of quantitation for this sample set were 0 01 mg total weight per filter and 1 7 µg of titanium per filter

Air samples for solvent vapors were taken by placing charcoal tubes (SKC 100/50 mg, lot 120) in a holder and using personal sampler pumps (Model 200, DuPont Inc ) to draw air through the charcoal tubes at 200 $cm^3$/min  Bulk samples of the two paints used in this study were analyzed by gas chromatography and mass spectroscopy  Four solvents, which had relatively large peaks during the gas chromatography - mass spectroscopy analysis, were selected as analytes for the charcoal tube samples  The amount of toluene, xylene isomers, n-butyl acetate, and ethyl acetate on the charcoal tubes were quantitated using NIOSH Methods 1450 and 1501 [14]  The concentrations of the four solvents were summed to compute a combined solvent concentration in terms of $mg/m^3$

Filter samples were taken at the four locations  on the worker, along the wall on the left side of booth, under the car door on the left side of the booth, and under the car door on the right side of the booth  All the filter samples were taken closed face except that both an open face and a closed faced sample were taken on the worker  A closed face sample has an inlet diameter of 4 mm  An open face cassette has the face cap removed and the inlet opening has diameter of 33 mm

Charcoal tube samples were collected at the same sampling locations as the filters  Two samples were taken under the left car door  One sample was a charcoal tube in charcoal tube holder, the other sample was a charcoal tube which was preceded by a 13 mm glass fiber filter (filter E133AG, Millipore, Bedford, MA)  The filter was in a filter holder (part SX 00013000, Millipore, Bedford, MA) with an inlet diameter of 4 mm  This was done to evaluate whether the paint aerosol, which contains solvent, may be penetrating the charcoal tubes [15]  The filter would provide a substrate to collect and evaporate the solvent

Paint Film Thickness Measurements

Paint film thickness was measured at these locations on the car  trunk, hood, roof, left door, and right door  At each location, a strip of 302 stainless steel shim stock, 40-45 cm long, 3 75 cm wide and 0 007±0 001 cm thick was taped to the car body surface  After the experimental run had been completed, the metal strip was removed  Once the paint had dried, film thicknesses were measured with a Fischerscope Multi 650 (Helmut Fischer GMBH+CO, Sindelfingen Germany) equipped with a magnetic probe (type GA 1 3)  This instrument is calibrated by placing films of known thickness on the surface of the metal test strip

Paint Mass

The mass of paint used was obtained by pre-weighing and post-weighing the spray gun on a balance (Model GT 4000 Ohaus)  The weight change is the amount of paint used

Spray Painting Booth Description

The autobody shell was painted in a DeVilbiss Concept II Downdraft Booth which had been modified  This booth illustrated schematically in Figure 2  The booth has a length of 24 feet  It uses two fans, one supplies air to the plenum above the filters in the ceiling  The other fan exhausts the air from the booth through the grates which run the full length of booth's floor  The filters in the ceiling are 16" x 46" and are contained in frames which are 18" x 48"  The pressure drop across these filters was measured to be 0 03" of

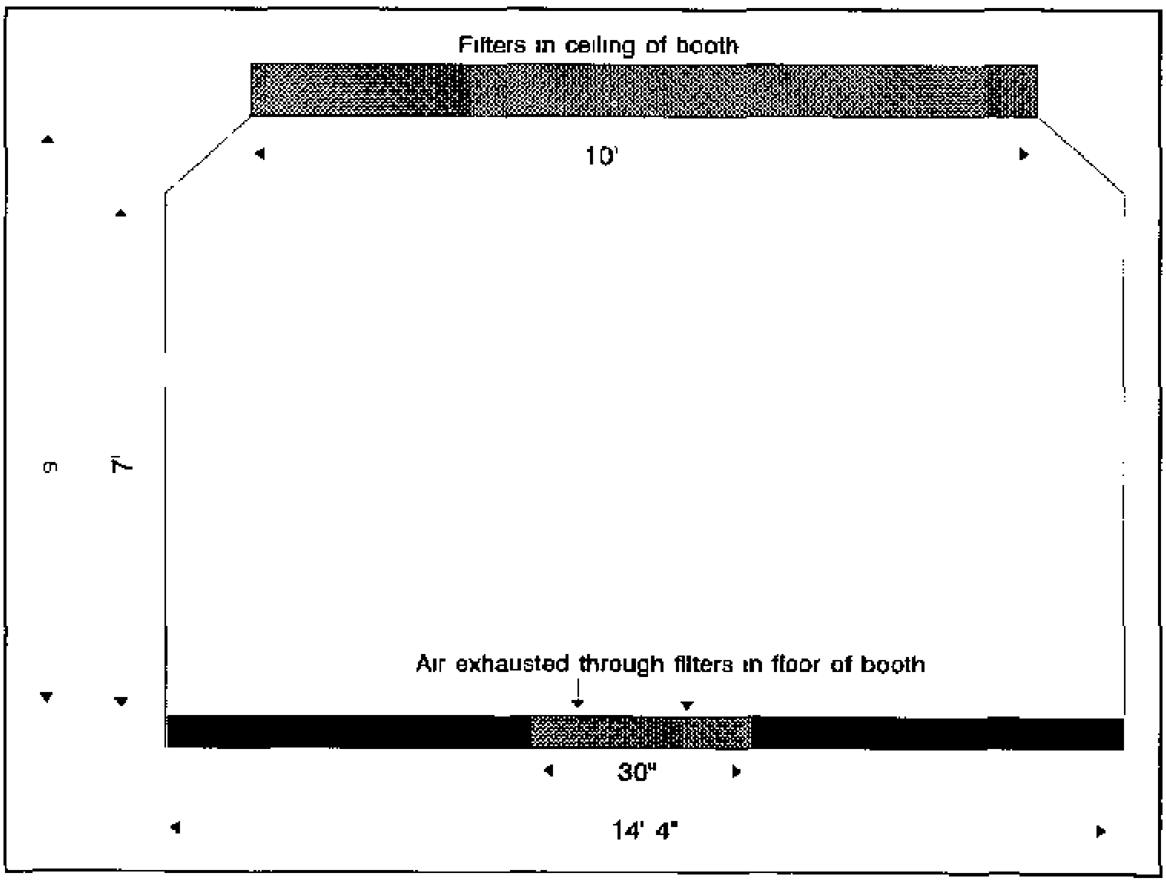



Figure 2  Cross sectional view of a spray painting booth during second set of tests  Instead of the normal two exhaust trenches, this booth has a single exhaust trench in the floor of the booth

water In order to simulate a poorly operated spray painting booth, the flow rates through the booth were deliberately reduced In addition, this booth had a single exhaust trench in the floor of the booth The standard booth has two exhaust trenches which would be under the car

Ventilation Measurements

Ventilation measurements were made to document the booth's performance and to understand how overspray is transported into the painter's breathing zone A thirty-six point pitot tube traverse was made to measure the air flow into the spray painting booth The average air velocity coming out of the ceiling filters was measured with a Balometer® (Niles, Ill) The Balometer® was held flush with the filters while the air flow through a 2' X 2' section was recorded These measurements were used to compute an average inlet velocity and an inlet air flow rate A velometer (Model 1440, Kurz, Carmel, CA) was used to measure air velocities around the car body shell at a height of 3' from the booth's floor and 12" and 18" from the car body shell Smoke tubes and helium-filled bubbles from a generator (Model 33, Sage Action, Ithaca, NY) were used to trace air flow patterns in the booth

Real-time Exposure Monitoring

During one spray painting operation, the painter's activities were recorded on video tape and his solvent exposures were monitored with a Photovac TIP II (PHOTOVAC Inc, Thornhill, Ontario) This was done to identify specific tasks which elevate the worker's exposure to the air contaminants [16 17] The analog output of the Microtip is proportional to the concentration of ionizable compounds in the air Because the instrument's response varies with the composition of the organic solvents in the air, the analog output, in volts, is reported Because of fire safety considerations, this instrument was located outside of the spray painting booth Teflon® tubing (Alltech Associates, Deerfield, IL), 0 125" inside diameter and 45' long, was attached to the worker in his breathing zone A personal sampler pump drew air through this tubing at 3 5 liters per minute and exhausted the sampled air into a glass tee The Photovac then sampled the air in this glass tee The analog output of the Photovac was recorded on a data logger (Rustrak® Ranger, Gulton, Inc , East Greenwich, RI)

## RESULTS AND FINDINGS

Booth Characterization

Figure 3 summarizes ventilation measurements and observations about the air flow pattern in the booth Pitot tube traverses in the supply air duct and the Balometer® measurements in the ceiling resulted in measured air flows of 5400 and 7100 cfm, respectively Based upon these two measurements, the downward air velocity from the ceiling is between 22-29 fpm Air flow patterns were studied with a car in the booth As the air flows around the car, the air flow accelerates to 30-70 fpm Smoke and helium bubbles released on top of a car stayed within 1-2' of the car and exited the booth through the exhaust slot in the floor of the booth

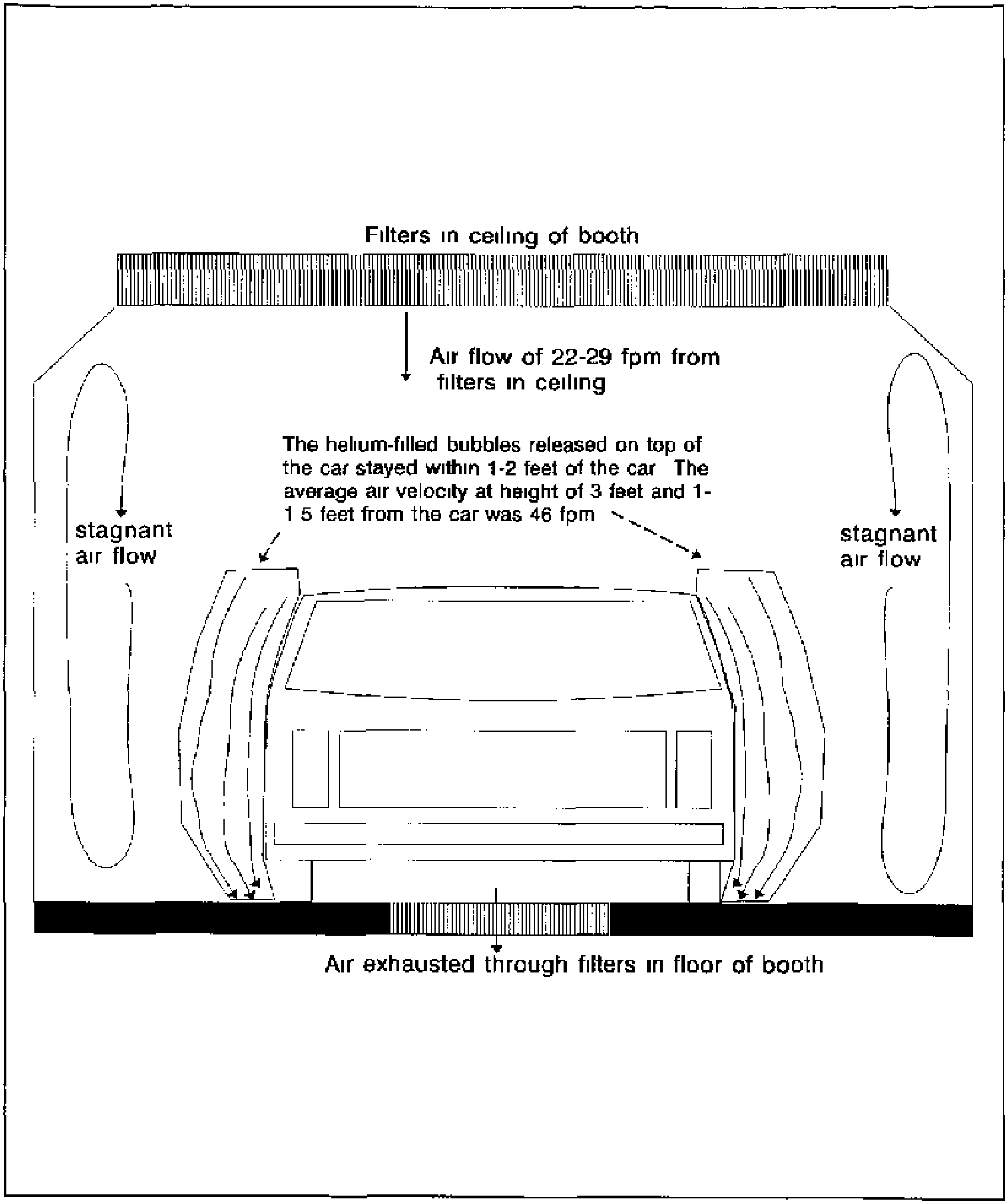



Figure 3 Schematic illustration of air flow patterns in booth The air flow rates were deliberately reduced from the design specification of 10,000 cfm to an air flow between 5400 and 7100 cfm

The air motion induced by the spray painting's jet apparently disrupts the air flows shown in Figure 3  Figure 4 summarizes the observed motion of helium-filled bubbles while a painter simulated painting the side of a car with an empty spray painting gun  When the spray painting gun is used, some helium-filled bubbles were transported toward the gun  This indicates that the spray painting gun can draw contaminated air towards the worker  The jet from the spray painting gun also dispersed other bubbles toward the front and back of the car  Jets are known to entrain additional air flow by transporting the

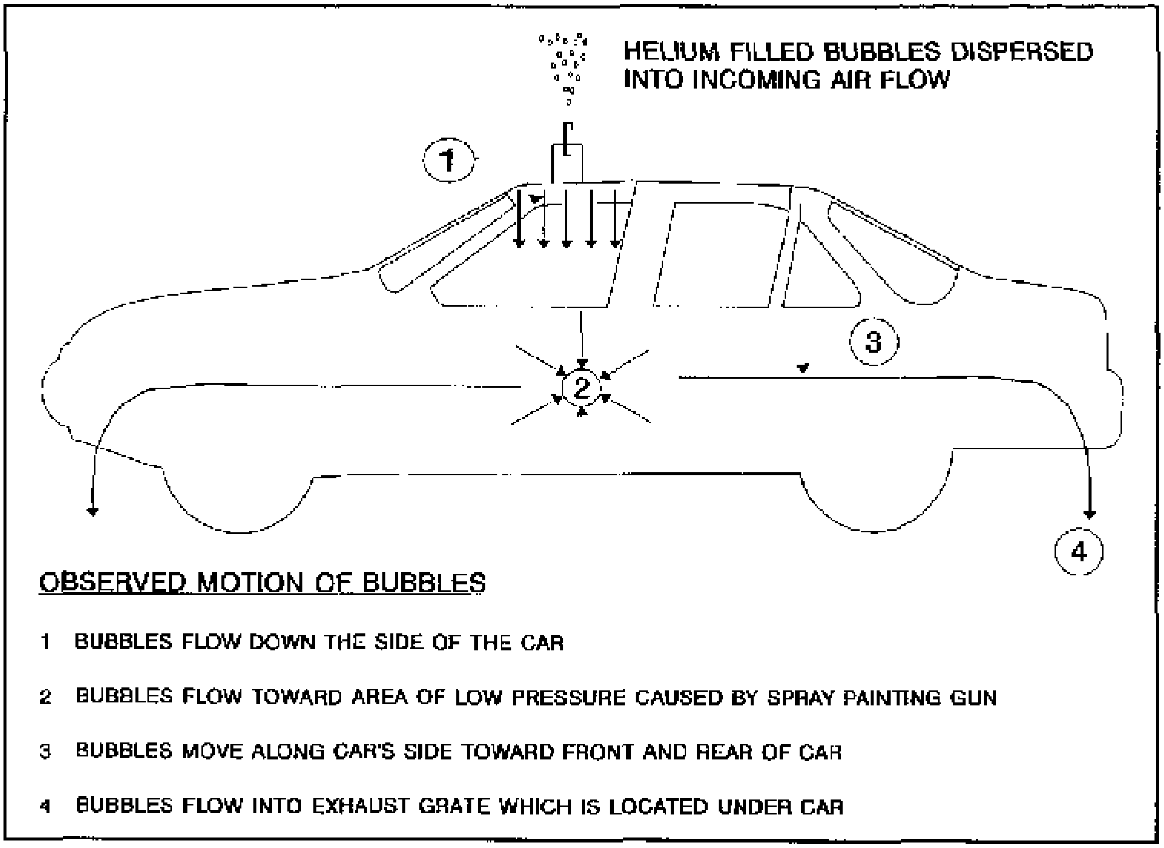



Figure 4  Motion of helium bubbles when the painter simulates painting side of car with empty spray painting guns

mechanical energy of the air flowing out the jet's nozzle to the surrounding air [18]  Apparently, the jet of air from the spray painting gun is inducing additional air motion that transports overspray toward the front or back of the car  When the energy of this jet is dispersed, the bubbles flowed toward the exhaust trench in the floor of the spray painting booth  This phenomena would tend to separate the worker from the overspray  The particulate overspray concentrations measured on the worker were an order of magnitude less than the concentrations measured elsewhere in the booth  (See Table C2 page 67 )  Thus, the downdraft design minimized overspray exposure by keeping the overspray away from the worker

The observed air motion in the booth suggests that the booths' ventilation prevents much of the overspray from entering the worker's breathing zone This booth minimizes worker overspray exposure by capturing the overspray after the energy of the jet is expended However, the air velocities caused by the spray painting gun appear to be much larger than the booth's air velocity Consequently, there is always the possibility that exposure occurs because a pocket of contaminated air moves into the worker's breathing zone

The real-time exposure monitoring results presented in Figure 5 are consistent with this interpretation of the ventilation data The analog output of the Photovac Tip II contains several sharp exposure peaks which occur during a variety of activities

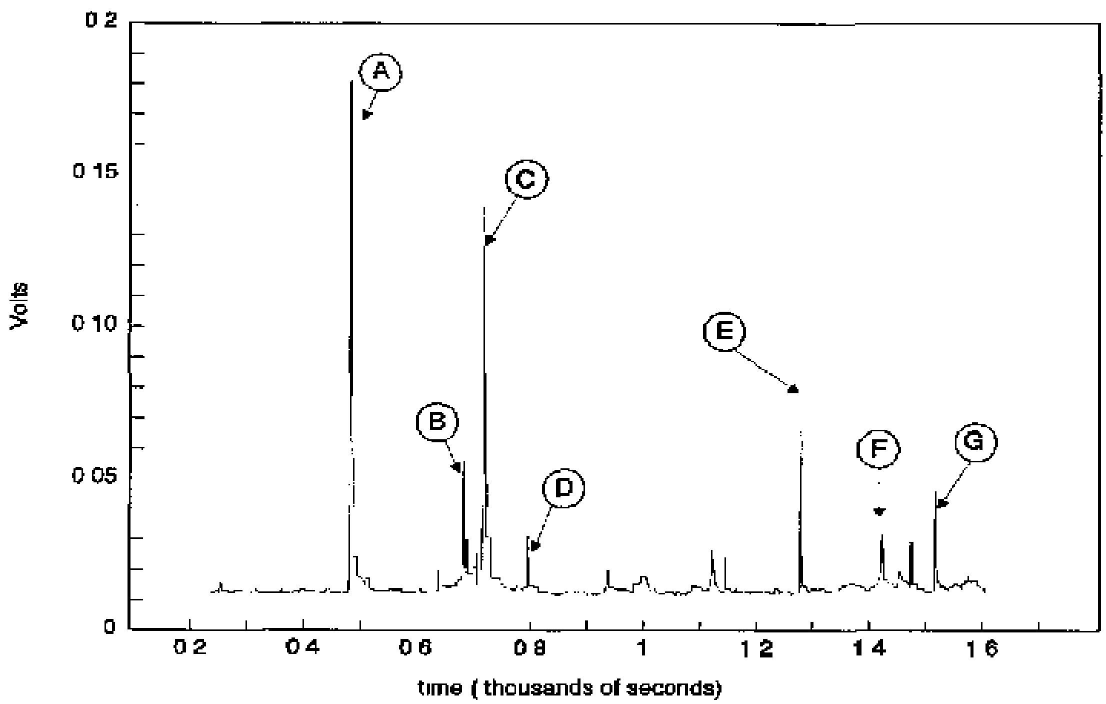
Effect of Spray Painting Gun Upon Dependent Variables

The effect of spray painting gun upon air contaminant concentrations was studied during two periods The data collected during the first sampling session, September 14-19, 1992, was discarded because of several problems which are discussed in Appendix A Appendix B contains the raw data collected during the second session, July 6-8, 1993 Appendix C contains the details of the statistical analysis used to evaluate whether spray painting gun affected the dependent variables

In order to ferret out the differences in the dependent variables attributable solely to the spray painting guns, the data analysis had to address the inconsistent paint usage The painter did not tightly control the mass of paint used during each experimental run He simply painted the car body so that the finish, in his professional opinion, looked good As a result, the observed differences in film thicknesses on the car and air contaminant concentrations are, to some extent, affected the use of different masses of paint during different sets of test conditions Varying the mass of paint applied to the surface will affect the other dependent variables in the study

In order to remove these mass-related affects, film thickness and air contaminant concentration data were normalized The average film thickness during each run was divided by the mass of paint used Because the average film thickness is directly proportional to the mass of paint which coats the car, this quotient is directly proportional to the transfer efficiency and this quotient is independent of mass of paint used Before performing statistical analysis, air contaminant concentrations were divided by film thickness Since film thickness is directly proportional to the mass of paint on the car body, differences in the air contaminant concentrations are evaluated on the basis of an equivalent paint job

The effects of paint, spray painting gun, and the interaction between spray painting gun and paint upon film thickness per mass of paint were evaluated by an analysis of variance (ANOVA) using the SAS General Linear Models (GLM) procedure (SAS Institute, Cary, NC) [19] Because air samples collected during the same experimental run may not be independent of each other, a repeated measures ANOVA was used for the concentration per film thickness data [20 21] Before the data analysis was conducted, the concentration data was log-transformed




A Routine painting the side of the car

B Painting the rear spoiler on the car

C Head close to bottom of door jam

D Head close to bottom of door jam

E Routine painting the side of the car

F Painting the rear spoiler

G Routincly Painting the side of the car

**Figure 5** Analog output of Photovac Tip II during spray painting with an HVLP spray painting gun

The probability that the observed differences were statistically significant are listed in Table 1 for the average value of film thickness divided by the mass of paint used This table shows that the interaction between the independent variables paint and spray painting gun significantly affected the film thickness per mass of paint Figure 6 shows the effect of spray painting gun upon the film thickness per mass of paint used varied with the paint The film thicknesses presented in Figure 6 are the least squares estimates of the means for this experiment Because the experiment was balanced and there is no missing data, the least squares estimates of the means are the same as the average For each paint, the GLM procedure computed t-statistics and probabilities for testing the hypothesis that spray painting gun does not effect the film thickness per mass of paint For paint A, the difference in spray painting guns is not significant (prob > t = 0 32) For paint B, the difference in the film thickness per mass of paint between the two guns was statistically significant (prob >t = 0 0005)

The choice of spray painting gun significantly affected the particulate overspray concentration/film thickness (prob > F = 0 0009) as presented in Table 1 (column 3) Because none of the interaction terms were statistically significant, the effect of gun upon the particulate overspray concentration does not vary with sampling location or paint to an extent large enough to be detected The effect of spray painting gun choice upon particulate overspray concentrations is presented in Figure 7

As shown in Figure 8, the combined solvent concentration measured on the worker differs significantly with the spray painting gun (Prob > F = 0 02) In addition, the gun-associated difference on the worker was much larger than the gun-associated difference at the other sampling locations (Prob >F = 0 006) In Table 1 for the variable combined solvent concentration/film thickness, the interaction between gun and sampling location was significant (Prob > F = 0 0002) This indicates that the effect of gun varies with the sampling location At the other locations, the difference was not significant

The effect of sampling location upon the combined solvent concentration was investigated using Tukey's HSD multiple comparison test This multiple comparison test showed that concentrations measured at the wall and on the worker differed from each other and all of the other sampling locations All of the other differences among locations were not significant

Finally, the repeated measures ANOVA indicated that spray painting gun did not have a significant affect upon titanium concentration divided by the film thickness The titanium content of the aerosol varied significantly with experimental run which increased the experimental variability, obscuring any effect that the spray painting gun had upon the observed titanium concentration per unit of film thickness

Table 1 Probability that chance caused the observed differences in the film thickness per mass of paint used and the normalized air contaminant concentrations

| Independent variables | Probability of a larger F, the probability that chance could have caused the observed differences in the dependent variables | | | |
|---|---|---|---|---|
| | Dependent variable/type of ANOVA | | | |
| | Film thickness/mass of paint used | Combined solvent concentration/film thickness | Particulate overspray concentration/film thickness | Titanium concentration/film thickness |
| | ordinary | repeated measures | repeated measures | repeated measures |
| paint | 0 08 | 0 4639 | 0 6126 | 0 5468 |
| gun | 0 0015 | 0 1813 | 0 0009 | 0 098 |
| gun*paint | 0 01 | 0 5299 | 0 5552 | 0 783 |
| location | NA | 0 0001 | 0 0001 | 0 0001 |
| gun*location | NA | 0 0002 | 0 5734 | 0 6165 |
| paint*location | NA | 0 125 | 0 6334 | 0 4472 |
| gun*paint*location | NA | 0 1511 | 0 4501 | 0 6460 |

NA - not applicable

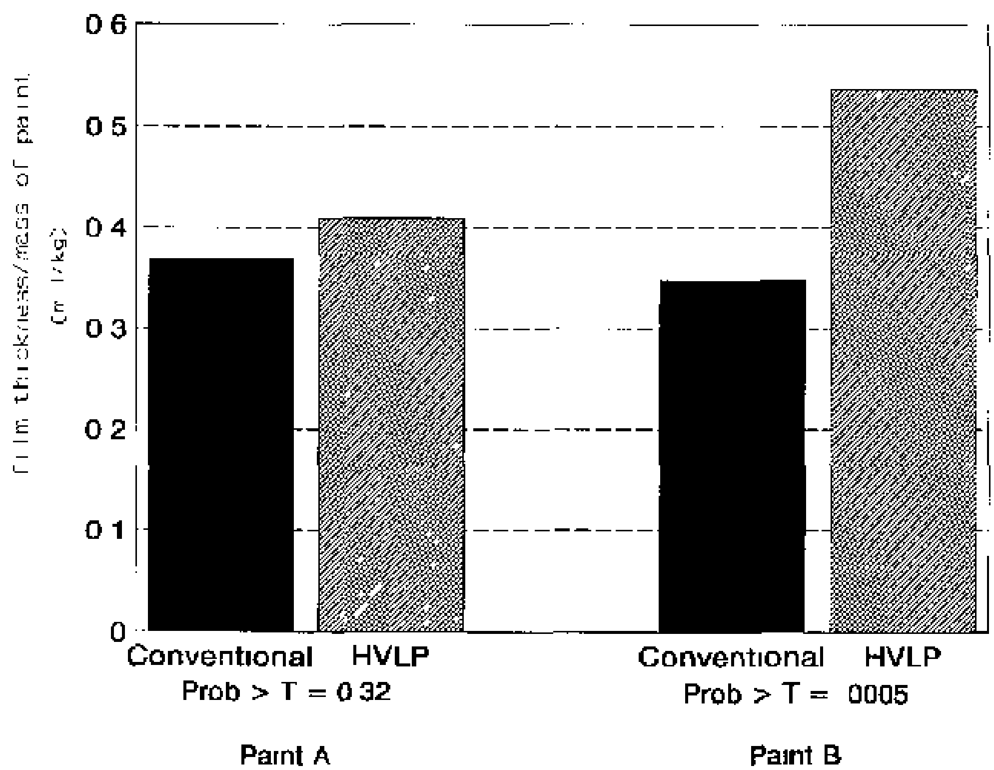



Figure 6 The effect of spray paint gun upon film thickness per mass of paint used varies with the paint tested

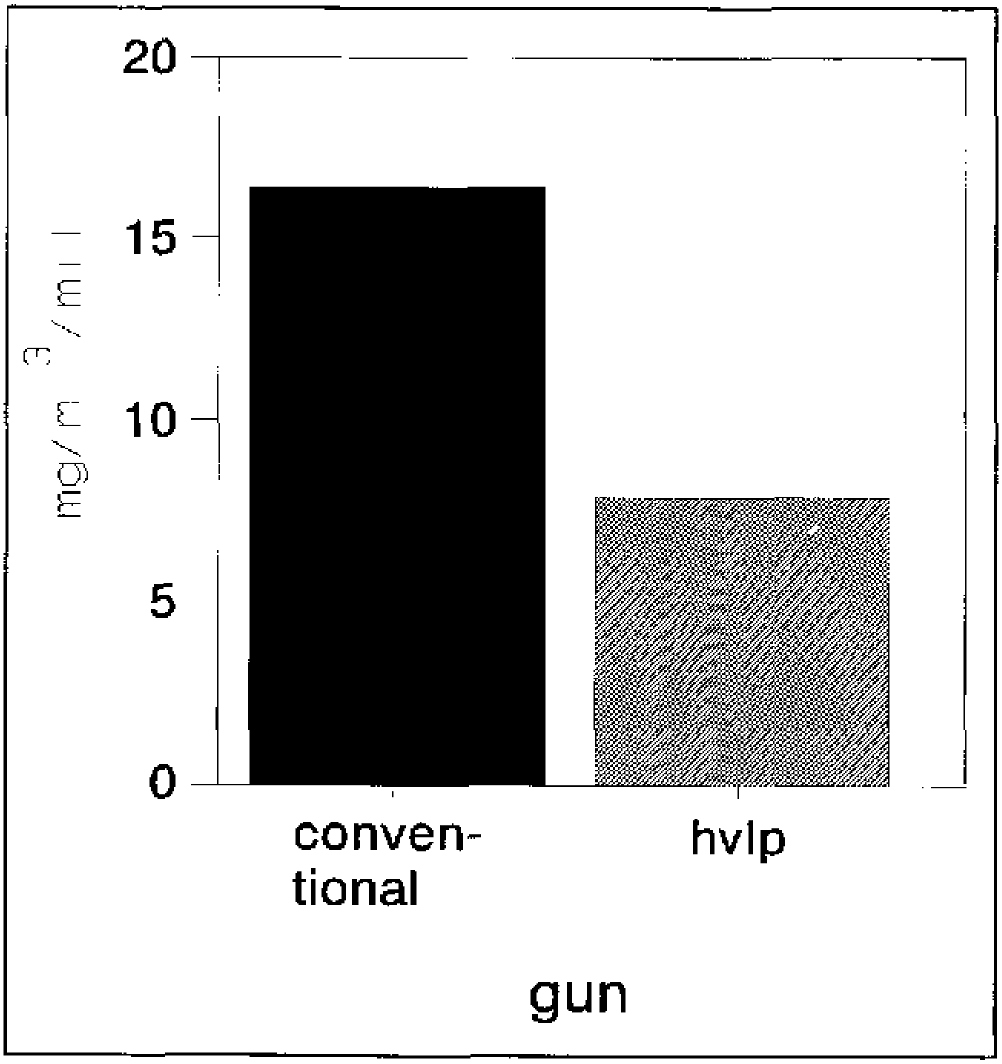



Figure 7 Effect of spray painting gun upon geometric mean particulate overspray concentration

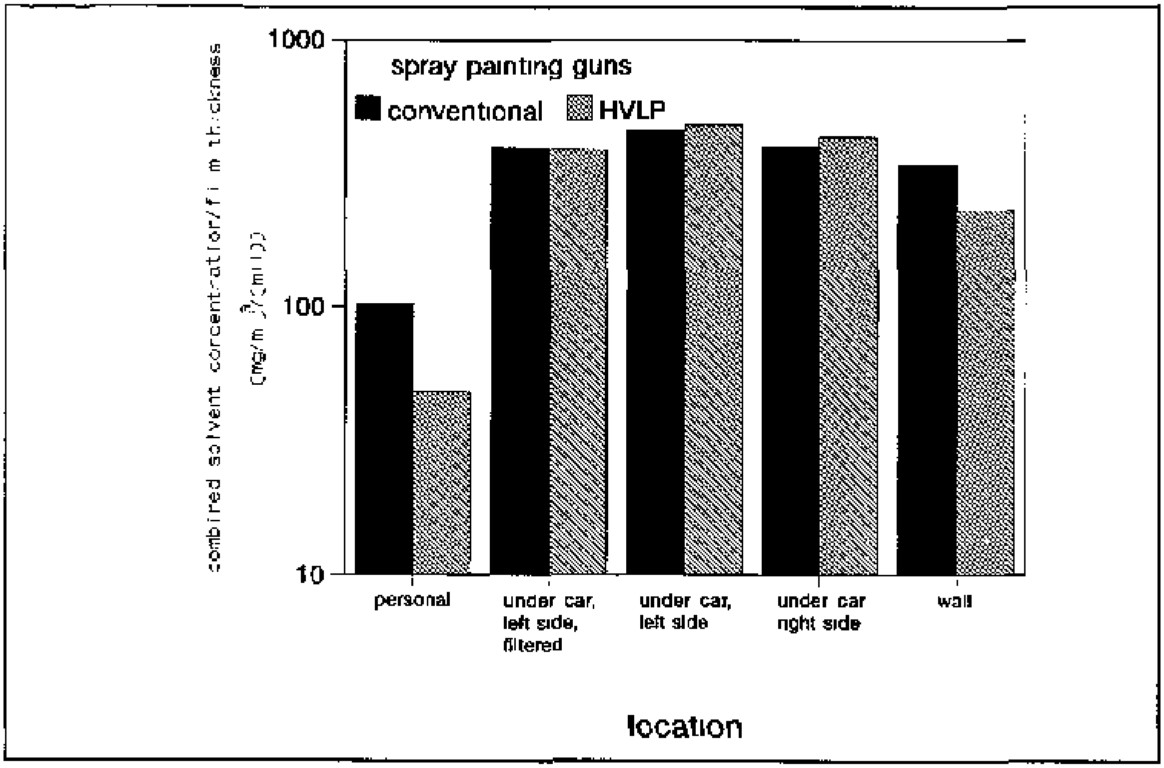



Figure 8 The effect of spray painting gun and location upon the geometric means of the combined solvent concentrations

## Discussion

Substituting the HVLP gun for the conventional gun caused a factor of 2 reduction in the particulate overspray concentration and about a 30 percent improvement in transfer efficiency Lingk reported a similar reduction in particulate overspray concentrations when a conventional spray painting gun was replaced with an HVLP spray painting gun [22] Anecdotal reports indicate that switching from conventional to HVLP spray painting guns reduces paint usage in autobody shops by about 25 percent [23,24] Clearly, minimizing the amount of overspray through gun selection is a useful option in addition to a spray painting booth for controlling worker exposure to overspray Because the air velocities from spray painting guns are much larger than the air velocities present in spray painting booths, spray painting booths may never be completely effective at separating the worker from the overspray

Figure 9 presents the observed and expected ratios of conventional to HVLP spray painting gun results for these variables film thickness per mass of paint used, combined solvent concentration per thickness of paint, and particulate overspray concentration per thickness of paint The error bars about observed ratios are the 95 percent confidence intervals Based upon claims in the commercial literature, conventional spray painting guns have a transfer efficiency of less than 0 4 and HVLP spray painting guns have transfer efficiency of at least 0 65 The expected ratio of the film thicknesses per mass of paint sprayed for the conventional spray painting gun to the result for the HVLP spray painting gun is less than ( 4/ 65) or 0 62 Because this value falls below the confidence interval for the observed ratio, substituting the HVLP gun for the conventional gun does not provide as much improvement in transfer efficiency as claimed in the commercial literature The expected ratios for the solvent and particulate overspray concentrations per paint thickness were obtained from the dimensionless concentrations presented in Figure 1 (explained on page 5) The noticeable difference between the observed and expected ratios for the solvent and particulate overspray concentrations per film thickness is a consequence of the smaller than expected difference in film thickness per mass of paint

In reviewing the available literature on spray painting, there were no references to data which substantiates the reported transfer efficiencies [1,2,3,23] Apparently, the reported estimates of transfer efficiency reflect "seat of pants" judgement rather than hard data Thus, one should not be surprised or alarmed by the smaller than expected difference between film thickness per mass of paint for the two spray painting guns This situation suggests a need to develop a standardized test for painting gun transfer efficiency In addition, fundamental knowledge about how spray painting parameters affect transfer efficiency are needed to evaluate the appropriateness of a transfer efficiency testing methodology

Conclusions/Recommendations

The use of HVLP spray painting guns needs to be encouraged The possible benefit of using HVLP spray painting guns compared to conventional guns needs to be considered along with other control options including ventilation and personal protective equipment

In reviewing the literature, there was an absence of any information that describes how an HVLP spray painting gun minimizes overspray production A physical model of overspray production would be very helpful It would allow equipment designers and users to knowledgeably select operating conditions which would minimize paint overspray generation Presently, such information is unavailable in the open scientific literature

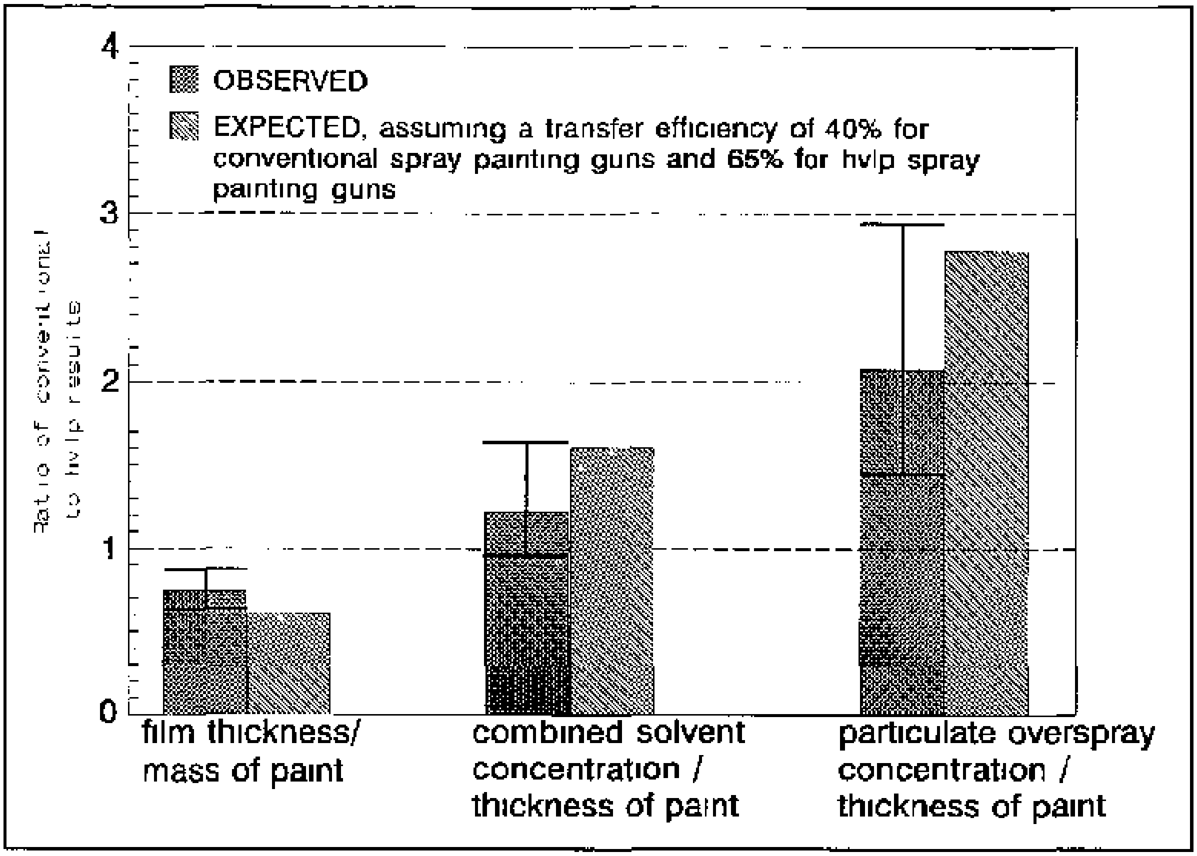



Figure 9 Observed and expected ratios of conventional to HVLP results The error bars are 95 % confidence intervals about the observed geometric mean

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## Appendix A

Description of Experimental Procedures and Listing and Air Contaminant Concentrations Measured, September 14-18, 1992

The data collected September 14-19, 1992, did not show that spray painting guns had a statistically significant effect upon air contaminant concentrations or transfer efficiency. However, the results from the first experiment were flawed and, if these results would have collected in a NIOSH laboratory, these results would not have been formally documented. The painter stated that the manner in which the experiment was conducted did not allow him to tell whether he was applying the proper amount of paint. The contrast between successive layers of paint was too small and he could not distinguish between freshly applied paint and the "old layer." Thus, the painting was done in an unrealistic manner. In addition, the particulate overspray concentrations were low and some filters lost weight. This was caused by a precision problem in the filter weighing procedure. The weight shift of blank filters for this study had a standard deviation of 0.05 mg versus 0.01 milligrams for the data discussed in the main body of the report. Thus, many particulate overspray concentrations measured on the worker and next to the booth wall were less than the estimated limit of detection (LOD). The LOD was estimated as three times the standard deviation of weight shift of the blanks. Because of these problems, this data is not believed to be useful, but it is included solely for the sake of completeness.

Experimental Procedures

This experiment involved 24 experimental runs. During each, the painter applied two coats of paint to the car body to simulate a complete painting job in an autobody shop. During each run, air contaminant concentrations, mass of paint used, painting times, and paint film thicknesses were measured. During the first 16 experimental runs, the painter switched between these two spray painting guns.

1. A siphon cup spray painting gun (DeVilbiss Model No. JGA 502-Tip 30EX).

2. A gravity-feed HVLP spray painting gun (DeVilbiss Model No. GFHV 501-33EX). In this spray painting gun, the pressure at the cap was measured to be 4.1 psig.

During experimental runs 17 - 24, the painter used a third spray painting gun.

3. A pressure feed HVLP spray painting gun (DeVilbiss Model No. 530-Tip 33FX). The pressure at the cap was measured to be 4.5 psig. In this gun, the paint cup was pressurized so that paint would flow from the cup to the atomization nozzle.

During experimental runs 1-20 a tan acrylic enamel (Centari Acrylic Enamel, Dupont, Willmington, DE) was used. By run 20, the supply of acrylic enamel was exhausted and a blue acrylic enamel was used.

Particulate overspray dust concentrations were measured using NIOSH Method 0500.[1] In this method, a known volume of air is drawn through a preweighed PVC filter at a flow rate of 5.0 liters per minute using a personal sampling pump (Aircheck Sampler, Model 224 -- PCXR7, SKC Inc, Eighty Four, PA). The weight gain of the filter is used to compute the milligrams of particulate overspray per cubic meter of air.

Air samples for solvent vapors were taken by placing charcoal tubes (SKC 100/50 mg, lot 120) in holders and using personal sampler pumps (Model 200, Dupont Inc ) to draw air through the charcoal tubes at 200 $cm^3$/min Bulk sample of the two paints used in this study and the reducer used to thin the paint were analyzed by gas chromatography and mass spectroscopy to select organic solvents for quantitation These four solvents, which had relatively large peaks during the gas chromatography - mass spectroscopy, were selected as analytes for the charcoal tube samples NIOSH Methods 1450 and 1501 were used to measure the mass of these solvents on the charcoal tube samples toluene, xylene isomers, and n-butyl acetate [2] The concentrations of these solvents were summed to compute a combined solvent concentration in terms of $mg/m^3$

The charcoal tube and filter samples were taken at the following locations on the worker, along the left side of booth, and under the car door on the left side of the booth

Paint Film Thickness Measurements

Paint film thickness was measured on the car's hood using the procedures described in the main body of the report

Spray Painting Booth Description

The autobody was painted in a DeVilbiss Concept II Downdraft Booth as described in the main body of the report The configuration of this booth is illustrated schematically in Figure 10

Tables A1, A2, and A3 list, respectively, the test conditions during each run, the solvent concentrations, and the particulate overspray concentrations In these tables, the following abbreviations were used to describe sampling locations

P - personal,
U - under the car, and,
W - next to the wall

The following abbreviations were used to describe spray painting guns during the first experiments

Conv The DeVilbiss Model JGA 502-30EX spray-painting gun,
HVLP The DeVilbiss Model GFHV 501-33EX gravity-feed spray painting gun, and,
PPOT The DeVilbiss Model 530-33FX pressure-feed HVLP spray painting gun

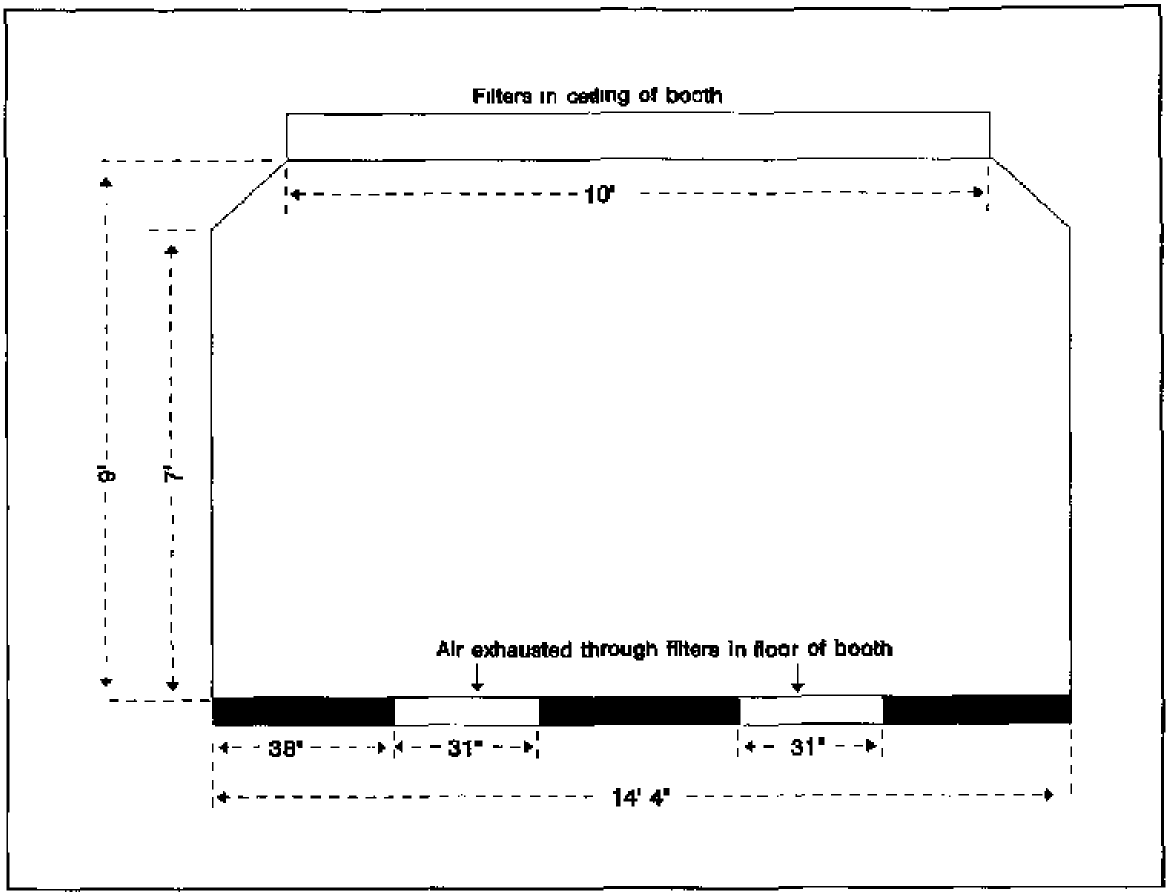


Figure 10 Cross section of spray painting booth during first set of tests

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Table A1

Test conditions and dependent variables for each experimental run, September 14-18, 1992

| Run | Gun code | Mass of paint used (grams) | Paint film thickness (mil) | Std dev of film thickness (mil) | Sampling time (min) | Painting time (min) | Painting time/ sampling time | Film thickness/ mass of paint (mils/kg of paint) | Paint usage rate (g/min) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Conv | 2365 2 | 1 61 | 0 110 | 14 | 9 | 0 643 | 0 681 | 262 8 |
| 2 | HVLP | 1703 2 | 1 15 | 0 110 | 23 | 17 | 0 739 | 0 675 | 100 2 |
| 3 | Conv | 2857 6 | 2 06 | 0 220 | 23 | 17 | 0 739 | 0 721 | 168 1 |
| 4 | HVLP | 2190 1 | 1 48 | 0 190 | 25 | 18 | 0 720 | 0 676 | 121.7 |
| 5 | Conv | 3020 2 | 2 16 | 0 190 | 18 | 13 | 0 722 | 0 715 | 232 3 |
| 6 | HVLP | 1981 7 | 1 32 | 0 140 | 25 | 16 | 0 640 | 0 666 | 123 9 |
| 7 | Conv | 3372 6 | 2 00 | 0 260 | 22 | 14 | 0 636 | 0 593 | 240 9 |
| 8 | HVLP | 2163 8 | 1 10 | 0 090 | 24 | 17 | 0 708 | 0 508 | 127 3 |
| 9 | Conv | 2915 6 | 2 01 | 0 180 | 22 | 14 | 0 636 | 0 689 | 208 3 |
| 10 | HVLP | 2183 9 | 1 36 | 0 160 | 25 | 20 | 0 800 | 0 623 | 109 2 |
| 11 | Conv | 2742 8 | 1 77 | 0 200 | 15 | 11 | 0 733 | 0 645 | 249 3 |
| 12 | HVLP | 2196 3 | 1 62 | 0 260 | 25 | 18 | 0 720 | 0 738 | 122 0 |
| 13 | Conv | 2972 3 | 2 18 | 0 260 | 17 | 11 | 0 778 | 0 733 | 141 5 |
| 14 | HVLP | 2222 9 | 1 46 | 0 130 | 24 | 16 | 0 667 | 0 657 | 138 9 |
| 15 | Conv | 3900 6 | 2 75 | 0 290 | 17 | 13 | 0 765 | 0 705 | 300 0 |
| 16 | HVLP | 2076 0 | 1 23 | 0 180 | 21 | 17 | 0 810 | 0 592 | 122 1 |
| 17 | PPot | 2709 6 | 1 72 | 0 130 | 16 | 11 | 0 687 | 0 635 | 246 3 |
| 18 | PPot | 2598 4 | 1 78 | 0 170 | 27 | 21 | 0 778 | 0 685 | 123 7 |
| 19 | PPot | 2173 7 | 1 61 | 0 090 | 13 | 10 | 0 769 | 0 741 | 217 4 |
| 20 | PPot | 2251 0 | 1 71 | 0 150 | 12 | 10 | 0 833 | 0 760 | 225 1 |

Table A1

Test conditions and dependent variables for each experimental run, September 14-18, 1992

| Run | Gun code | Mass of paint used (grams) | Paint film thickness (mil) | Std dev of film thickness (mil) | Sampling time (min) | Painting time (min) | Painting time/ sampling time | Film thickness/ mass of paint (mils/kg of paint) | Paint usage rate (g/min) |
|---|---|---|---|---|---|---|---|---|---|
| 21 | PPot | 2594 7 | 1 73 | 0 150 | 16 | 13 | 0 812 | 0 667 | 199 6 |
| 22 | PPot | 2188 0 | 1 37 | 0 150 | 12 | 10 | 0 833 | 0 626 | 218 8 |
| 23 | PPot | 2474 2 | 1 77 | 0 120 | 16 | 13 | 0 812 | 0 715 | 190 3 |
| 24 | PPot | 2150 4 | 1 38 | 0 120 | 13 | 10 | 0 769 | 0 642 | 215 0 |

Table A2  Listing of Solvent Concentrations, September 14-18, 1992

| Run | Gun code | Sampling location code | Pump times | | Sampling time (min) | Painting time (min) | Concentration (ppm) | | | Combined solvent concentration (mg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Start | Stop | | | Toluene | Xylene | Butyl acetate | |
| 1 | Conv | P | 09 53 am | 10 10 am | 14 | 9 | 3 61 | 2 47 | 0 75 | 27 86 |
| 1 | Conv | U | 09 50 am | 10 10 am | 14 | 9 | 51 25 | 71 67 | 30 11 | 646 43 |
| 1 | Conv | W | 09 50 am | 10 10 am | 14 | 9 | 5 13 | 4 37 | 2 26 | 48 93 |
| 2 | HVLP | P | 10 22 am | 10 47 am | 23 | 17 | 1 73 | 1 00 | 0 46 | 13 04 |
| 2 | HVLP | U | 10 15 am | 10 46 am | 23 | 17 | 32 93 | 55 16 | 21 54 | 465 22 |
| 2 | HVLP | W | 10 20 am | 10 46 am | 23 | 17 | 1 73 | 1 00 | 0 00 | 10 87 |
| 3 | Conv | P | 10 58 am | 11 25 am | 23 | 17 | 3 47 | 2 26 | 0 92 | 27 17 |
| 3 | Conv | U | 10 54 am | 11 25 am | 23 | 17 | 63 55 | 90 26 | 42 61 | 832 61 |
| 3 | Conv | W | 10 54 am | 11 25 am | 23 | 17 | 2 72 | 2 21 | 0 92 | 24 13 |
| 4 | HVLP | P | 11 25 am | 11 52 am | 25 | 18 | 2 07 | 1 61 | 0 84 | 18 80 |
| 4 | HVLP | U | 11 24 am | 11 52 am | 25 | 18 | 15 95 | 17 53 | 8 43 | 176 00 |
| 4 | HVLP | W | 11 24 am | 11 52 am | 25 | 18 | 2 02 | 1 38 | 0 42 | 15 60 |
| 5 | Conv | P | 01 08 pm | 01 30 pm | 18 | 13 | 3 47 | 2 50 | 1 17 | 29 44 |
| 5 | Conv | U | 01 10 pm | 01 30 pm | 18 | 13 | 64 23 | 83 29 | 39 23 | 788 89 |
| 5 | Conv | W | 01 10 pm | 01 30 pm | 18 | 13 | 2 21 | 1 92 | 1 17 | 22 22 |
| 6 | HVLP | P | 01 38 pm | 02 05 pm | 25 | 16 | 2 39 | 2 17 | 0 84 | 22 40 |
| 6 | HVLP | U | 01 35 pm | 02 05 pm | 25 | 16 | 18 07 | 19 38 | 9 70 | 198 00 |
| 6 | HVLP | W | 01 35 pm | 02 05 pm | 25 | 16 | 1 06 | 0 92 | 0 00 | 8 00 |
| 7 | Conv | P | 02 10 pm | 02 34 pm | 22 | 14 | 3 20 | 2 20 | 0 96 | 26 14 |
| 7 | Conv | U | 02 10 pm | 02 34 pm | 22 | 14 | 24 16 | 22 02 | 11 98 | 243 18 |
| 7 | Conv | W | 02 10 pm | 02 34 pm | 22 | 14 | 2 72 | 2 04 | 0 96 | 23 64 |

Table A2 Listing of Solvent Concentrations, September 14-18, 1992

| Run | Gun code | Sampling location code | Pump times | | Sampling time (min) | Painting time (min) | Concentration (ppm) | | | Combined solvent concentration (mg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Start | Stop | | | Toluene | Xylene | Butyl acetate | |
| 8 | HVLP | P | 02 40 pm | 03 06 pm | 24 | 17 | 1 99 | 1 68 | 0 88 | 18 96 |
| 8 | HVLP | U | 02 40 pm | 03 06 pm | 24 | 17 | 48 72 | 81 69 | 38 20 | 718 75 |
| 8 | HVLP | W | 02 40 pm | 03 06 pm | 24 | 17 | 0 55 | 0 48 | 0 00 | 4 17 |
| 9 | Conv | P | 08 38 am | 09 04 am | 22 | 14 | 2 90 | 2 41 | 0 96 | 25 91 |
| 9 | Conv | U | 08 37 am | 09 04 am | 22 | 14 | 66 44 | 89 12 | 41 20 | 831 82 |
| 9 | Conv | W | 08 37 am | 09 04 am | 22 | 14 | 3 99 | 3 41 | 1 63 | 37 50 |
| 10 | HVLP | P | 09 08 am | 09 36 am | 25 | 20 | 1 59 | 1 38 | 0 42 | 14 00 |
| 10 | HVLP | U | 09 08 am | 09 36 am | 25 | 20 | 1 06 | 0 92 | 0 00 | 8 00 |
| 10 | HVLP | W | 09 08 am | 09 36 am | 25 | 20 | 45 71 | 69 20 | 30 77 | 618 00 |
| 11 | Conv | P | 09 39 am | 10 02 am | 15 | 11 | 3 81 | 2 31 | 0 70 | 27 67 |
| 11 | Conv | U | 09 39 am | 10 02 am | 15 | 11 | 97.45 | 130 71 | 61 13 | 1223 33 |
| 11 | Conv | W | 09 39 am | 10 02 am | 15 | 11 | 3 37 | 2 92 | 1 41 | 32 00 |
| 12 | HVLP | P | 10 06 am | 10 37 am | 25 | 18 | 1 06 | 0 92 | 0 42 | 10 00 |
| 12 | HVLP | U | 10 05 am | 10 37 am | 25 | 18 | 58 47 | 92 26 | 42 16 | 820 00 |
| 12 | HVLP | W | 10 05 am | 10 37 am | 25 | 18 | 1 06 | 0 92 | 0 00 | 8 00 |
| 13 | Conv | P | 10 45 am | 11 04 am | 17 | 11 | 0 98 | 0 85 | 0 00 | 7 41 |
| 13 | Conv | U | 10 39 am | 11 04 am | 17 | 11 | 73 82 | 93 97 | 39 03 | 870 37 |
| 13 | Conv | W | 10 39 am | 11 04 am | 17 | 11 | 1 48 | 1 28 | 0 39 | 12 96 |
| 14 | HVLP | P | 11 07 am | 11 35 am | 24 | 16 | 1 83 | 1 44 | 0 44 | 15 21 |
| 14 | HVLP | U | 11 06 am | 11 35 am | 24 | 16 | 71 98 | 105 72 | 52 69 | 979 17 |
| 14 | HVLP | W | 11 06 am | 11 35 am | 24 | 16 | 1 11 | 0 96 | 0 00 | 8 33 |

Table A2 Listing of Solvent Concentrations, September 14-18, 1992

| Run | Gun code | Sampling location code | Pump times | | Sampling time (min) | Painting time (min) | Concentration (ppm) | | | Combined solvent concentration (mg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Start | Stop | | | Toluene | Xylene | Butyl acetate | |
| 15 | Conv | P | 01 42 pm | 02 03 pm | 17 | 13 | 1 56 | 1 36 | 0 62 | 14 71 |
| 15 | Conv | U | 01 41 pm | 02 02 pm | 17 | 13 | 101 61 | 128 90 | 68 19 | 1264 71 |
| 15 | Conv | W | 01 41 pm | 02 02 pm | 17 | 13 | 7 35 | 5 90 | 3 10 | 67 94 |
| 16 | HVLP | P | 02 06 pm | 02 29 pm | 21 | 17 | 0 63 | 1 10 | 0 00 | 7 14 |
| 16 | HVLP | U | 02 05 pm | 02 29 pm | 21 | 17 | 53 78 | 65 90 | 33 12 | 645 24 |
| 16 | HVLP | W | 02 05 pm | 02 29 pm | 21 | 17 | 2 21 | 1 81 | 1 00 | 20 95 |
| 17 | PPot | P | 08 07 am | 08 27 am | 16 | 11 | 2 49 | 2 16 | 0 66 | 21 88 |
| 17 | PPot | U | 08 07 am | 08 28 am | 16 | 11 | 83 05 | 86 50 | 44 13 | 896 88 |
| 18 | PPot | P | 08 31 am | 08 54 am | 27 | 21 | 3 79 | 1 45 | 0 78 | 24 26 |
| 18 | PPot | U | 08 31 am | 08 55 am | 27 | 21 | 59 06 | 64 07 | 32 79 | 655 56 |
| 18 | PPot | W | 08 31 am | 08 55 am | 27 | 21 | 3 64 | 2 73 | 1 33 | 31 85 |
| 19 | PPot | P | 08 59 am | 09 13 am | 13 | 10 | 3 78 | 1 77 | 0 00 | 21 92 |
| 19 | PPot | W | 08 58 am | 09 13 am | 13 | 10 | 5 01 | 4 26 | 1 62 | 45 00 |
| 20 | PPot | P | 09 16 am | 09 30 am | 12 | 10 | 3 76 | 1 92 | 0 88 | 26 67 |
| 20 | PPot | U | 09 15 am | 09 30 am | 12 | 10 | 102 98 | 124 94 | 59 72 | 1212 50 |
| 20 | PPot | W | 09 15 am | 09 30 am | 12 | 10 | 6 64 | 5 67 | 2 63 | 62 08 |
| 21 | PPot | P | 09 31 am | 09 57 am | 16 | 13 | 5 56 | 3 03 | 1 32 | 40 31 |
| 21 | PPot | U | 09 33 am | 09 57 am | 16 | 13 | 107 97 | 158 58 | 57 30 | 1365 63 |
| 21 | PPot | W | 09 33 am | 09 57 am | 16 | 13 | 6 81 | 5 91 | 1 98 | 60 63 |
| 22 | PPot | P | 09 59 am | 10 16 am | 12 | 10 | 5 20 | 2 88 | 0 88 | 36 25 |
| 22 | PPot | U | 09 57 am | 10 17 am | 12 | 10 | 121 81 | 163 38 | 57 96 | 1441 67 |

Table A2 Listing of Solvent Concentrations, September 14-18, 1992

| Run | Gun code | Sampling location code | Pump times | | Sampling time (min) | Painting time (min) | Concentration (ppm) | | | Combined solvent concentration (mg/m³) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Start | Stop | | | Toluene | Xylene | Butyl acetate | |
| 22 | PPot | W | 09 57 am | 10 17 am | 12 | 10 | 7 31 | 5 29 | 1 76 | 58 75 |
| 23 | PPot | P | 10 18 am | 10 38 am | 16 | 13 | 4 82 | 3 03 | 1 32 | 37 50 |
| 23 | PPot | U | 10 20 am | 10 38 am | 16 | 13 | 116 27 | 158 58 | 61 26 | 1415 63 |
| 23 | PPot | W | 10 20 am | 10 38 am | 16 | 13 | 7 81 | 5 12 | 1 98 | 60 94 |
| 24 | PPot | P | 10 38 am | 10 57 am | 13 | 10 | 5 01 | 2 66 | 0 81 | 34 23 |
| 24 | PPot | U | 10 39 am | 10 57 am | 13 | 10 | 102 22 | 141 94 | 51 88 | 1246 15 |
| 24 | PPot | W | 10 39 am | 10 57 am | 13 | 10 | 9 10 | 6 83 | 2 43 | 75 38 |

Table A3 Particulate overspray concentrations - September 14-19, 1992

| Run | Gun code | Location code | Concentration (mg/m$^3$) |
|---|---|---|---|
| 1 | Conv | P | 0 43 |
| 1 | Conv | U | 70 29 |
| 1 | Conv | W | 9 86 |
| 2 | HVLP | P | 0 96 |
| 2 | HVLP | U | 27 04 |
| 2 | HVLP | W | 0 09 |
| 3 | Conv | P | 2 87 |
| 3 | Conv | U | 33 22 |
| 3 | Conv | W | 4 43 |
| 4 | HVLP | P | 0 16 |
| 4 | HVLP | U | 38 24 |
| 4 | HVLP | W | 1 44 |
| 5 | Conv | P | 3 44 |
| 5 | Conv | U | 49 11 |
| 5 | Conv | W | 6 22 |
| 6 | HVLP | P | 2 16 |
| 6 | HVLP | U | 48 56 |
| 6 | HVLP | W | 0 64 |
| 7 | Conv | P | 1 18 |
| 7 | Conv | U | 44 45 |
| 7 | Conv | W | 2 82 |
| 8 | HVLP | P | 2 42 |
| 8 | HVLP | U | 46 33 |
| 8 | HVLP | W | 0 50 |
| 9 | Conv | P | 3 82 |
| 9 | Conv | U | 45 36 |
| 9 | Conv | W | 4 73 |
| 10 | HVLP | P | 2 88 |
| 10 | HVLP | U | 45 20 |
| 10 | HVLP | W | 0 88 |
| 11 | Conv | P | 2 80 |

Table A3  Particulate overspray concentrations - September 14-19, 1992

| Run | Gun code | Location code | Concentration (mg/m³) |
|---|---|---|---|
| 11 | Conv | U | 79 87 |
| 11 | Conv | W | 11 07 |
| 12 | HVLP | P | 0 80 |
| 12 | HVLP | U | 51 44 |
| 12 | HVLP | W | 1 04 |
| 13 | Conv | P | 16 15 |
| 13 | Conv | U | 43 33 |
| 13 | Conv | W | 2 07 |
| 14 | HVLP | P | 0 42 |
| 14 | HVLP | U | 57 42 |
| 14 | HVLP | W | 3 50 |
| 15 | Conv | P | 0 47 |
| 15 | Conv | U | 107 18 |
| 15 | Conv | W | 10 71 |
| 16 | HVLP | P | 1 52 |
| 16 | HVLP | U | 63 05 |
| 16 | HVLP | W | 3 62 |
| 17 | PPot | P | 4 63 |
| 17 | PPot | U | 76 88 |
| 17 | PPot | W | 10 38 |
| 18 | PPot | P | 0 04 |
| 18 | PPot | U | 49 78 |
| 18 | PPot | W | 4 52 |
| 19 | PPot | P | 1 69 |
| 19 | PPot | U | 83 08 |
| 19 | PPot | W | 6 62 |
| 20 | PPot | P | 1 83 |
| 20 | PPot | U | 90 50 |
| 20 | PPot | W | 12 83 |
| 21 | PPot | P | 0 38 |
| 21 | PPot | U | back up pad missing |

| Table A3 Particulate overspray concentrations - September 14-19, 1992 | | | |
|---|---|---|---|
| Run | Gun code | Location code | Concentration (mg/m³) |
| 21 | PPot | W | 10 50 |
| 22 | PPot | P | 1 33 |
| 22 | PPot | U | 93 33 |
| 22 | PPot | W | 2 67 |
| 23 | PPot | P | 0 50 |
| 23 | PPot | U | 77 88 |
| 23 | PPot | W | 7 63 |
| 24 | PPot | P | 0 92 |
| 24 | PPot | U | 80 15 |
| 24 | PPot | W | 11 54 |

## Appendix B

### Data Tables for Data Collected July 6-8, 1993

Table B1  Individual values of film thickness and summary statistics on film thickness

| R | L | AVG | S | Individual values of film thickness in mils along length of test strip | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | r | 0 55 | 0 05 | 0 58 | 0 58 | 0 48 | 0 57 | 0 55 | 0 47 | 0 63 | 0 62 | 0 47 | 0 54 | 0 52 | 0 53 | 0 58 | 0 53 |
| 1 | t | 0 70 | 0 12 | 0 53 | 0 66 | 0 62 | 0 54 | 0 58 | 0 66 | 0 83 | 0 96 | 0 62 | 0 73 | 0 85 | 0 75 | 0 75 | |
| 1 | h | 0 66 | 0 04 | 0 63 | 0 67 | 0 57 | 0 65 | 0 7 | 0 68 | 0 66 | 0 73 | 0 66 | 0 63 | 0 69 | 0 68 | 0 65 | 0 6 |
| 1 | dl | 0 52 | 0 13 | 0 6 | 0 57 | 0 68 | 0 69 | 0 68 | 0 63 | 0 54 | 0 48 | 0 4 | 0 46 | 0 33 | 0 36 | 0 31 | |
| 1 | dr | 0 50 | 0 09 | 0 4 | 0 46 | 0 35 | 0 41 | 0 47 | 0 47 | 0 56 | 0 56 | 0 61 | 0 63 | 0 59 | 0 51 | | |
| 2 | ld | 0 40 | 0 04 | 0 35 | 0 43 | 0 31 | 0 44 | 0 42 | 0 41 | 0 36 | 0 41 | 0 42 | 0 4 | 0 41 | 0 41 | 0 45 | 0 34 |
| 2 | rd | 0 39 | 0 08 | 0 27 | 0 31 | 0 32 | 0 36 | 0 41 | 0 46 | 0 45 | 0 4 | 0 45 | 0 45 | 0 52 | 0 31 | 0 42 | 0 27 |
| 2 | r | 0 66 | 0 06 | 0 75 | 0 73 | 0 7 | 0 57 | 0 75 | 0 66 | 0 64 | 0 71 | 0 7 | 0 58 | 0 66 | 0 63 | 0 63 | 0 56 |
| 2 | h | 0 48 | 0 05 | 0 53 | 0 45 | 0 43 | 0 49 | 0 53 | 0 59 | 0 48 | 0 45 | 0 44 | 0 42 | 0 43 | 0 47 | | |
| 2 | t | 0 50 | 0 11 | 0 53 | 0 51 | 0 42 | 0 23 | 0 36 | 0 45 | 0 48 | 0 54 | 0 58 | 0 59 | 0 65 | 0 63 | 0 59 | |
| 3 | ld | 1 05 | 0 10 | 0 95 | 1 15 | 1 11 | 1 17 | 1 17 | 1 18 | 1 08 | 1 | 1 02 | 1 | 1 | 1 03 | 0 88 | 0 91 |
| 3 | h | 0 84 | 0 09 | 0 9 | 0 82 | 0 86 | 0 87 | 0 88 | 0 9 | 1 03 | 0 86 | 0 94 | 0 77 | 0 76 | 0 77 | 0 67 | 0 71 |
| 3 | r | 0 52 | 0 06 | 0 56 | 0 57 | 0 45 | 0 48 | 0 44 | 0 47 | 0 56 | 0 51 | 0 46 | 0 5 | 0 55 | 0 62 | 0 6 | 0 5 |
| 3 | t | 1 03 | 0 10 | 1 04 | 1 13 | 1 | 1 17 | 1 06 | 1 09 | 1 05 | 1 15 | 1 1 | 1 05 | 0 9 | 0 88 | 0 85 | 0 88 |

Abbreviations  R - run number, L - location on car, AVG - average film thickness (mils), S - standard deviation of film thickness (mils), t - trunk, h - hood, r - roof, ld - left door, rd - right door

Table B1 Individual values of film thickness and summary statistics on film thickness

| R | L | AVG | S | Individual values of film thickness in mils along length of test strip | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | rd | 0 89 | 0 05 | 0 91 | 0 96 | 0 86 | 0 82 | 0 92 | 0 96 | 0 97 | 0 85 | 0 82 | 0 87 | 0 95 | 0 86 | 0 91 | 0 81 | |
| 4 | t | 0 89 | 0 16 | 0 68 | 0 77 | 0 78 | 0 84 | 0 91 | 1 04 | 1 07 | 1 25 | 0 98 | 0 84 | 0 78 | 0 74 | | | |
| 4 | rd | 0 67 | 0 10 | 0 63 | 0 7 | 0 78 | 0 71 | 0 77 | 0 8 | 0 79 | 0 6 | 0 59 | 0 59 | 0 6 | 0 47 | | | |
| 4 | ld | 0 69 | 0 11 | 0 42 | 0 57 | 0 61 | 0 6 | 0 67 | 0 74 | 0 68 | 0 75 | 0 75 | 0 78 | 0 84 | 0 84 | 0 69 | 0 69 | |
| 4 | h | 0 81 | 0 09 | 0 6 | 0 85 | 0 89 | 0 9 | 0 92 | 0 81 | 0 78 | 0 76 | 0 75 | 0 79 | | | | | |
| 4 | r | 0 69 | 0 08 | 0 64 | 0 56 | 0 59 | 0 65 | 0 68 | 0 68 | 0 72 | 0 7 | 0 69 | 0 7 | 0 78 | 0 83 | 0 81 | | |
| 5 | r | 0 59 | 0 05 | 0 53 | 0 59 | 0 54 | 0 52 | 0 61 | 0 59 | 0 59 | 0 64 | 0 62 | 0 66 | 0 63 | 0 51 | | | |
| 5 | ld | 0 54 | 0 07 | 0 44 | 0 47 | 0 47 | 0 49 | 0 56 | 0 46 | 0 54 | 0 63 | 0 63 | 0 63 | 0 59 | | | | |
| 5 | h | 0 76 | 0 10 | 0 8 | 0 93 | 0 74 | 0 74 | 0 79 | 0 91 | 0 78 | 0 7 | 0 74 | 0 67 | 0 54 | | | | |
| 5 | rd | 0 69 | 0 08 | 0 6 | 0 64 | 0 78 | 0 79 | 0 76 | 0 64 | 0 66 | 0 73 | 0 74 | 0 72 | 0 52 | | | | |
| 5 | t | 0 75 | 0 08 | 0 67 | 0 71 | 0 68 | 0 75 | 0 74 | 0 8 | 0 76 | 0 85 | 0 83 | 0 88 | 0 68 | 0 62 | | | |
| 6 | rd | 0 65 | 0 08 | 0 59 | 0 65 | 0 7 | 0 7 | 0 71 | 0 62 | 0 62 | 0 71 | 0 73 | 0 7 | 0 42 | | | | |
| 6 | r | 0 52 | 0 06 | 0 46 | 0 47 | 0 52 | 0 58 | 0 63 | 0 51 | 0 61 | 0 54 | 0 5 | 0 42 | 0 48 | 0 5 | | | |
| 6 | h | 0 66 | 0 09 | 0 51 | 0 51 | 0 54 | 0 66 | 0 69 | 0 77 | 0 78 | 0 76 | 0 7 | 0 67 | 0 66 | | | | |

Abbreviations R - run number, L - location on car, AVG - average film thickness (mils), S - standard deviation of film thickness (mils), t - trunk, h - hood, r - roof, ld - left door, rd - right door

Table B1  Individual values of film thickness and summary statistics on film thickness

| R | L | AVG | S | Individual values of film thickness in mils along length of test strip | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | ld | 0 62 | 0 17 | 0 33 | 0 42 | 0 47 | 0 61 | 0 58 | 0 55 | 0 65 | 0 83 | 0 9 | 0 8 | 0 72 | | | | |
| 6 | t | 0 80 | 0 07 | 0 65 | 0 7 | 0 8 | 0 84 | 0 75 | 0 82 | 0 8 | 0 82 | 0 9 | 0 91 | 0 78 | | | | |
| 7 | r | 0 96 | 0 10 | 0 73 | 0 87 | 0 9 | 0 97 | 0 87 | 1 02 | 1 09 | 1 06 | 1 07 | 0 99 | 1 01 | 0 96 | | | |
| 7 | rd | 0 64 | 0 07 | 0 6 | 0 68 | 0 56 | 0 67 | 0 57 | 0 66 | 0 66 | 0 73 | 0 72 | 0 72 | 0 5 | | | | |
| 7 | t | 0 98 | 0 09 | 0 94 | 1 04 | 1 | 0 97 | 1 06 | 1 14 | 1 02 | 0 92 | 0 99 | 0 84 | 0 83 | | | | |
| 7 | h | 0 66 | 0 08 | 0 71 | 0 71 | 0 68 | 0 8 | 0 76 | 0 68 | 0 61 | 0 6 | 0 56 | 0 61 | 0 57 | | | | |
| 7 | ld | 0 65 | 0 06 | 0 56 | 0 65 | 0 7 | 0 63 | 0 7 | 0 67 | 0 72 | 0 63 | 0 72 | 0 6 | 0 66 | 0 5 | | | |
| 8 | h | 1 00 | 0 14 | 0 88 | 0 97 | 0 9 | 0 8 | 0 97 | 1 06 | 1 27 | 1 14 | 1 08 | 1 11 | 1 05 | 0 81 | | | |
| 8 | t | 1 06 | 0 13 | 0 9 | 0 92 | 1 03 | 1 16 | 0 86 | 0 96 | 1 03 | 1 2 | 1 3 | 1 2 | 1 11 | 1 02 | | | |
| 8 | ld | 0 80 | 0 06 | 0 81 | 0 82 | 0 74 | 0 9 | 0 85 | 0 78 | 0 85 | 0 85 | 0.84 | 0 79 | 0,77 | 0 76 | 0 65 | | |
| 8 | rd | 0 76 | 0 09 | 0 78 | 0 83 | 0 83 | 0 9 | 0 88 | 0 79 | 0 68 | 0 65 | 0 74 | 0 64 | 0 63 | | | | |
| 8 | r | 0 82 | 0 13 | 0 97 | 1 06 | 0 97 | 0 76 | 0 86 | 0 7 | 0 69 | 0 75 | 0 67 | 0 81 | | | | | |
| 9 | ld | 0 53 | 0 09 | 0 34 | 0 49 | 0 64 | 0 64 | 0 52 | 0 6 | 0 64 | 0 55 | 0 5 | 0 46 | 0 57 | 0 45 | | | |
| 9 | r | 0 67 | 0 05 | 0 67 | 0 73 | 0 75 | 0 68 | 0 72 | 0 72 | 0 69 | 0 62 | 0 64 | 0 67 | 0 58 | 0 57 | 0 63 | | |

Abbreviations  R - run number, L - location on car, AVG - average film thickness (mils), S - standard deviation of film thickness (mils), t - trunk, h - hood, r - roof, ld - left door, rd - right door

Table B1  Individual values of film thickness and summary statistics on film thickness

| R | L | AVG | S | Individual values of film thickness in mils along length of test strip | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | h | 0 71 | 0 06 | 0 68 | 0 68 | 0 63 | 0 59 | 0 68 | 0 65 | 0 8 | 0 77 | 0 74 | 0 69 | 0 82 | 0 73 | 0 74 | | |
| 9 | rd | 0 64 | 0 11 | 0 57 | 0 74 | 0 81 | 0 8 | 0 73 | 0 69 | 0 63 | 0 65 | 0 69 | 0 58 | 0 48 | 0 54 | 0 45 | | |
| 9 | t | 0 93 | 0 11 | 0 88 | 0 81 | 0 87 | 0 87 | 0 9 | 0 92 | 0 94 | 0 91 | 0 92 | 1 17 | 1 16 | 0 9 | 0 84 | | |
| 10 | r | 0 63 | 0 06 | 0 57 | 0 58 | 0 56 | 0 58 | 0 56 | 0 64 | 0 69 | 0 62 | 0 68 | 0 71 | 0 68 | 0 66 | 0 74 | 0 55 | |
| 10 | rd | 0 49 | 0 11 | 0 27 | 0 41 | 0 42 | 0 61 | 0 66 | 0 61 | 0 63 | 0 53 | 0 54 | 0 48 | 0 43 | 0 43 | 0 41 | 0 43 | |
| 10 | h | 0 90 | 0 19 | 0 64 | 0 68 | 0 67 | 0 78 | 0 89 | 1 08 | 1 11 | 1 14 | 1 16 | 1 15 | 0 97 | 0 79 | 0 74 | 0 8 | |
| 10 | ld | 0 62 | 0 13 | 0 47 | 0 47 | 0 59 | 0 82 | 0 72 | 0 9 | 0 74 | 0 66 | 0 64 | 0 62 | 0 59 | 0 5 | 0 45 | 0 51 | |
| 10 | t | 1 13 | 0 15 | 0 89 | 0 81 | 1 | 1 14 | 1 34 | 1 33 | 1 15 | 1 15 | 1 16 | 1 3 | 1 17 | 1 1 | 1 09 | | |
| 11 | t | 0 87 | 0 10 | 0 95 | 0 8 | 0 67 | 0 73 | 0 79 | 0 93 | 0 91 | 0 98 | 0 87 | 0 9 | 1 01 | 0 96 | 0 91 | 0 79 | |
| 11 | r | 0 53 | 0 08 | 0 52 | 0 54 | 0 66 | 0 51 | 0 5 | 0 54 | 0 63 | 0 64 | 0 55 | 0 52 | 0 42 | 0 35 | | | |
| 11 | ld | 0 58 | 0 11 | 0 44 | 0 45 | 0 44 | 0 48 | 0 55 | 0 59 | 0 69 | 0 8 | 0 58 | 0 63 | 0 68 | 0 59 | | | |
| 11 | h | 0 71 | 0 14 | 0 6 | 0 55 | 0 7 | 0 66 | 0 56 | 0 8 | 0 97 | 0 7 | 0 92 | 0 79 | 0 79 | 0 5 | | | |
| 11 | rd | 0 60 | 0 08 | 0 59 | 0 6 | 0 67 | 0 53 | 0 56 | 0 55 | 0 54 | 0 58 | 0 56 | 0 77 | 0 76 | 0 52 | | | |
| 12 | h | 1 12 | 0 14 | 1 04 | 1 15 | 1 35 | 1 37 | 1 37 | 1 18 | 1 15 | 1 03 | 0 94 | 1 02 | 1 02 | 1 1 | 1 | 1 01 | 1 1 |

Abbreviations  R - run number, L - location on car, AVG - average film thickness (mils), S - standard deviation of film thickness (mils), t - trunk, h - hood, r - roof, ld - left door, rd - right door

Table B1  Individual values of film thickness and summary statistics on film thickness

| R | L | AVG | S | Individual values of film thickness in mils along length of test strip | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | t | 1 16 | 0 18 | 1 12 | 1 14 | 1 05 | 1 28 | 1 48 | 1 45 | 1 41 | 1 15 | 1 05 | 1 03 | 0 97 | 0 92 | 1 07 | | |
| 12 | rd | 0 95 | 0 09 | 0 76 | 0 89 | 1 01 | 1 06 | 1 02 | 1 07 | 1 05 | 0 96 | 0 9 | 0 9 | 0 9 | 0 86 | | | |
| 12 | r | 0 77 | 0 15 | 1 03 | 0 95 | 1 02 | 0 83 | 0 81 | 0 75 | 0 68 | 0 73 | 0.76 | 0 85 | 0 72 | 0.63 | 0 56 | 0.5 | |
| 12 | ld | 1 02 | 0 15 | 0 64 | 0 88 | 1 07 | 1 13 | 1 15 | 1 13 | 1 03 | 1 1 | 1 14 | 1 07 | 1 14 | 1 03 | 0 77 | | |
| 13 | rd | 0 55 | 0 12 | 0 33 | 0 46 | 0 62 | 0 56 | 0 47 | 0 52 | 0 62 | 0 72 | 0 84 | 0 65 | 0 56 | 0 54 | 0 47 | 0 51 | 0 51 |
| 13 | h | 0 86 | 0 08 | 0 72 | 0 79 | 0 83 | 0 97 | 0 93 | 0 9 | 0 94 | 0 86 | 0 95 | 0 78 | 0 92 | 0 94 | 0 89 | 0 75 | 0 75 |
| 13 | t | 0 98 | 0 12 | 0 79 | 0 9 | 0 81 | 0 79 | 1 | 1 14 | 1 1 | 0 97 | 0 98 | 1 07 | 0 94 | 1 11 | 1 16 | 1 04 | 0 85 |
| 13 | ld | 0 57 | 0 11 | 0 34 | 0 4 | 0 46 | 0 5 | 0 61 | 0 56 | 0 62 | 0 59 | 0 67 | 0 75 | 0 63 | 0 62 | 0 7 | 0 55 | |
| 13 | r | 0 68 | 0 14 | 1 03 | 0 93 | 0 78 | 0 71 | 0 69 | 0 71 | 0 7 | 0 6 | 0 59 | 0 59 | 0 52 | 0 6 | 0 57 | 0 56 | |
| 14 | t | 0 95 | 0 15 | 0 83 | 0 89 | 1 23 | 1 19 | 1 07 | 1 01 | 1 1 | 0 87 | 0 76 | 0 72 | 0 86 | 1 02 | 0 87 | 0 94 | |
| 14 | ld | 0 71 | 0 11 | 0 46 | 0 58 | 0 75 | 0 75 | 0 72 | 0 82 | 0 8 | 0 77 | 0 81 | 0 73 | 0 65 | 0 67 | 0 84 | 0 56 | |
| 14 | rd | 0 72 | 0 13 | 0 46 | 0 64 | 0 94 | 0 81 | 0 84 | 0 76 | 0 94 | 0 86 | 0 64 | 0 64 | 0 64 | 0 61 | 0 74 | 0 69 | 0 56 |
| 14 | r | 0 75 | 0 10 | 0 93 | 0 89 | 0 82 | 0 85 | 0 78 | 0 76 | 0 64 | 0 75 | 0 81 | 0 77 | 0 7 | 0 66 | 0 58 | 0 65 | 0 7 |
| 14 | h | 0 65 | 0 07 | 0 56 | 0 75 | 0 77 | 0 66 | 0 67 | 0 76 | 0 68 | 0 61 | 0 65 | 0 54 | 0 7 | 0 59 | 0 59 | 0 6 | |

Abbreviations  R - run number, L - location on car, AVG - average film thickness (mils), S - standard deviation of film thickness (mils), t - trunk, h - hood, r - roof, ld - left door, rd - right door

Table B1 Individual values of film thickness and summary statistics on film thickness

| R | L | AVG | S | Individual values of film thickness in mils along length of test strip | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | r | 0 58 | 0 07 | 0 64 | 0 67 | 0 68 | 0 64 | 0 59 | 0 48 | 0 54 | 0 45 | 0 47 | 0 54 | 0 59 | 0 62 | 0 61 | 0 66 | |
| 15 | t | 0 83 | 0 14 | 0 66 | 0 74 | 0 79 | 0 82 | 0 89 | 0 89 | 1 07 | 1 11 | 0 86 | 0 84 | 0 62 | 0 64 | 0 9 | | |
| 15 | ld | 0 59 | 0 13 | 0 43 | 0 53 | 0 49 | 0 56 | 0 6 | 0 46 | 0 7 | 0 68 | 0 75 | 0 86 | 0 72 | 0 59 | 0 49 | 0 38 | |
| 15 | rd | 0 64 | 0 10 | 0 46 | 0 57 | 0 67 | 0 77 | 0 7 | 0 62 | 0 58 | 0 62 | 0 56 | 0 79 | 0 74 | 0 78 | 0 5 | | |
| 15 | h | 0 57 | 0 09 | 0 52 | 0 48 | 0 56 | 0 63 | 0 75 | 0 7 | 0 71 | 0 49 | 0 59 | 0 5 | 0 5 | 0 49 | 0 48 | | |
| 16 | ld | 0 79 | 0 09 | 0 64 | 0 71 | 0 91 | 0 94 | 0 83 | 0 83 | 0 74 | 0 84 | 0 81 | 0 81 | 0 79 | 0 85 | 0 62 | | |
| 16 | r | 0 84 | 0 07 | 0 9 | 0 95 | 0 81 | 0 79 | 0 83 | 0 8 | 0 84 | 0 74 | 0 88 | 0 97 | 0 8 | 0 72 | | | |
| 16 | t | 1 13 | 1 12 | 1 23 | 1 17 | 1 16 | 1 3 | 1 28 | 1 34 | 1 23 | 1 13 | 1 09 | 1 1 | 0 91 | 0 88 | 0 87 | | |
| 16 | rd | 0 82 | 0 83 | 0 7 | 0 78 | 0 84 | 0 85 | 0 91 | 0 87 | 0 92 | 0 89 | 0 91 | 0 9 | 0 73 | 0 73 | 0 66 | | |
| 16 | h | 0 97 | 0 98 | 0 86 | 0 88 | 0 99 | 1 06 | 1 03 | 1 15 | 1 25 | 1 05 | 1 | 0 83 | 0 88 | 0 88 | 0 75 | | |

Abbreviations R - run number, L - location on car, AVG - average film thickness (mils), S - standard deviation of film thickness (mils), t - trunk, h - hood, r - roof, ld - left door, rd - right door

Table B2 Listing of test conditions, dependent variables and anova results for evaluating whether test conditions affected dependent variables

| Run | Gun | Paint | Sampling time (min) | Painting time (min) | Mass of paint (grams) | Average film thickness (mill) | Average Film thickness/ mass of paint (mils/kg) | Painting time/ sampling time |
|---|---|---|---|---|---|---|---|---|
| 1 | h | a | 14 83 | 8 63 | 1618 1 | 0 58 | 0 36 | 0 58 |
| 2 | c | b | 15 88 | 10 23 | 1802 4 | 0 49 | 0 27 | 0 64 |
| 3 | c | a | 16 50 | 10 72 | 2112 5 | 0 86 | 0 41 | 0 65 |
| 4 | h | b | 13 60 | 10 03 | 1717 3 | 0 75 | 0 44 | 0 74 |
| 5 | h | a | 13 28 | 10 15 | 1632 3 | 0 66 | 0 41 | 0 76 |
| 6 | c | b | 14 72 | 9 23 | 1786 1 | 0 65 | 0 36 | 0 63 |
| 7 | c | a | 16 80 | 9 00 | 1898 6 | 0 78 | 0 41 | 0 54 |
| 8 | h | b | 14 40 | 9 60 | 1586 8 | 0 89 | 0 56 | 0 67 |
| 9 | h | a | 14 17 | 9 50 | 1636 0 | 0 70 | 0 43 | 0 67 |
| 10 | c | b | 13 78 | 9 67 | 1983 2 | 0 75 | 0 38 | 0 70 |
| 11 | c | a | 13 58 | 9 68 | 1959 2 | 0 66 | 0 34 | 0 71 |
| 12 | h | b | 13 72 | 9 60 | 1612 4 | 1 01 | 0 62 | 0 70 |
| 13 | h | a | 13 35 | 9 32 | 1635 5 | 0 73 | 0 45 | 0 70 |
| 14 | c | b | 14 97 | 10 48 | 1983 2 | 0 76 | 0 38 | 0 70 |
| 15 | c | a | 18 85 | 9 22 | 1996 8 | 0 64 | 0 32 | 0 49 |

Abbreviations C - conventional, gravity fed spray painting gun, h - gravity fed HVLP spray painting gun

Table B2 Listing of test conditions, dependent variables and anova results for evaluating whether test conditions affected dependent variables

| Run | Gun | Paint | Sampling time (min) | Painting time (min) | Mass of paint (grams) | Average film thickness (mill) | Average Film thickness/ mass of paint (mils/kg) | Painting time/ sampling time |
|---|---|---|---|---|---|---|---|---|
| 16 | h | b | 15 25 | 9 70 | 1727 7 | 0 91 | 0 53 | 0 64 |
| Test conditions (independent variables) | | | Probability of a larger F statistic (this is the probability of seeing such large differences due to chance) | | | | | |
| paint | | | 0 34 | 0 44 | 0 38 | see Appendix C for repeated measures analysis | 0 08 | 0 31 |
| gun | | | 0 03 | 0 32 | 0 001 | | 0 0015 | 0 19 |
| paint*gun | | | 0 15 | 0 68 | 0 11 | | 0 02 | 0 4 |

Abbreviations C - conventional, gravity fed spray painting gun, h - gravity fed HVLP spray painting gun

| Table B3 Particulate Overspray and Titanium Concentrations | | | |
|---|---|---|---|
| Run | Location | Particulate overspray concentration (mg/m$^3$) | Titanium concentration ($\mu g/m^3$) |
| 1 | UCL | 23 04 | 284 49 |
| 1 | PCF | 0 39 | 0 00 |
| 1 | UCR | 14 01 | 80 90 |
| 1 | WAL | 7 40 | 75 51 |
| 1 | POF | 0 30 | 0 00 |
| 2 | UCL | 37 89 | 312 28 |
| 2 | WAL | 17 49 | 332 42 |
| 2 | UCR | 28 70 | 328 65 |
| 2 | PCF | 4 02 | 117 10 |
| 2 | POF | 2 38 | 36 52 |
| 3 | WAL | 25 44 | 244 85 |
| 3 | UCL | 36 35 | 275 15 |
| 3 | UCR | 26 17 | 281 21 |
| 3 | PCF | 3 62 | 89 70 |
| 3 | POF | 3 38 | 235 15 |
| 4 | UCL | 30 28 | 697 06 |
| 4 | WAL | 14 10 | 427 94 |
| 4 | UCR | 14 10 | 133 82 |
| 4 | PCF | 2 34 | 75 00 |
| 4 | POF | 3 22 | 35 29 |
| 5 | WAL | 11 88 | 944 04 |
| 5 | UCL | 20 61 | 584 19 |
| 5 | UCR | 15 49 | 316 19 |
| 5 | PCF | 2 09 | 118 95 |
| 5 | POF | 2 09 | 132 50 |
| 6 | WAL | 13 98 | 342 47 |
| 6 | UCL | 30 83 | 2588 90 |

Abbreviations UCL - under car left, UCR - under car right, W - wall, POF - personal sample open face, PCF personal sample, closed face

| Table B3 Particulate Overspray and Titanium Concentrations | | | |
|---|---|---|---|
| Run | Location | Particulate overspray concentration (mg/m³) | Titanium concentration (μg/m³) |
| 6 | UCR | 20 91 | 269 08 |
| 6 | PCF | 3 25 | 213 36 |
| 6 | POF | 1 34 | 0 00 |
| 7 | WAL | 21 65 | 3295 24 |
| 7 | UCL | 34 03 | 3233 33 |
| 7 | UCR | 20 58 | 1870 24 |
| 7 | PCF | 1 77 | 160 71 |
| 7 | POF | 1 77 | 100 00 |
| 8 | PCF | 1 51 | 125 00 |
| 8 | POF | 3 18 | 0 00 |
| 8 | UCL | 23 46 | 3022 22 |
| 8 | WAL | 9 15 | 784 72 |
| 8 | UCR | 16 23 | 1215 28 |
| 9 | PCF | 0 83 | 241 41 |
| 9 | WAL | 25 82 | 944 47 |
| 9 | POF | 1 96 | 38 12 |
| 9 | UCL | 35 84 | 1872 00 |
| 9 | UCR | 18 62 | 1619 29 |
| 10 | WAL | 27 70 | 6239 42 |
| 10 | UCL | 59 48 | 12029 02 |
| 10 | UCR | 26 10 | 5209 19 |
| 10 | PCF | 3 03 | 470 13 |
| 10 | POF | 1 73 | 66 75 |
| 11 | WAL | 25 46 | 2079 02 |
| 11 | UCL | 56 97 | 3601 47 |
| 11 | UCR | 15 00 | 1425 28 |
| 11 | PCF | 4 25 | 369 57 |

Abbreviations UCL - under car left, UCR - under car right, W - wall, POF - personal sample open face, PCF personal sample, closed face

| Table B3 Particulate Overspray and Titanium Concentrations | | | |
|---|---|---|---|
| Run | Location | Particulate overspray concentration (mg/m³) | Titanium concentration (µg/m³) |
| 11 | POF | 4 40 | 167 85 |
| 12 | UCL | 23 60 | 2834 51 |
| 12 | WAL | 8 59 | 1412 88 |
| 12 | UCR | 11 94 | 1011 91 |
| 12 | PCF | 5 09 | 195 38 |
| 12 | POF | 0 13 | 72 90 |
| 13 | WAL | 19 31 | 3146 07 |
| 13 | UCL | 18 26 | 3910 11 |
| 13 | UCR | 39 98 | 8764 04 |
| 13 | PCF | 1 48 | 292 13 |
| 13 | POF | 0 73 | 119 85 |
| 14 | UCL | 64 66 | 11385 30 |
| 14 | WAL | 27 11 | 6414 25 |
| 14 | UCR | 22 70 | 5465 48 |
| 14 | PCF | 4 13 | 435 63 |
| 14 | POF | 1 86 | 62 81 |
| 15 | UCL | 44 02 | 9336 87 |
| 15 | PCF | 1 58 | 625 99 |
| 15 | WAL | 31 18 | 6376 66 |
| 15 | UCR | 25 24 | 3978 78 |
| 15 | POF | 10 92 | 180 37 |
| 16 | WAL | 26 08 | 226 89 |
| 16 | PCF | 0 25 | 0 00 |
| 16 | UCR | 16 51 | 3200 00 |
| 16 | UCL | 42 61 | 148 20 |
| 16 | POF | 2 61 | 146 89 |

Abbreviations UCL - under car left, UCR - under car right, W - wall, POF - personal sample open face, PCF personal sample, closed face

| Table B4 Solvent concentrations | | | | | | |
|---|---|---|---|---|---|---|
| Run | Location | Ethyl acetate (ppm) | Toluene (ppm) | Xylenes (ppm) | n-Butyl acetate (ppm) | Combined solvent concentration (mg/m³) |
| 1 | WAL | LT 1 9 | 6 89 | 3 73 | 4 24 | 62 36 |
| 1 | UCR | 1 87 | 42 04 | 31 83 | 29 69 | 444 94 |
| 1 | UCL | 1 87 | 27 73 | 17 08 | 16 96 | 266 29 |
| 1 | UCF | 1 87 | 26 84 | 17 08 | 16 26 | 259 55 |
| 1 | POF | 0 94 | 3 22 | 0 78 | 1 41 | 25 62 |
| 2 | WAL | 1 75 | 15 04 | 10 88 | 9 90 | 157 40 |
| 2 | UCR | 1 75 | 37 59 | 34 08 | 30 36 | 440 71 |
| 2 | UCL | 1 75 | 20 89 | 13 78 | 13 86 | 210 91 |
| 2 | UCF | 0 87 | 12 53 | 9 43 | 8 58 | 132 21 |
| 2 | POF | 1 75 | 4 34 | 2 18 | 1 98 | 41 55 |
| 3 | WAL | 1 68 | 17 69 | 12 56 | 11 44 | 181 82 |
| 3 | UCR | 1 68 | 21 71 | 16 75 | 14 61 | 230 30 |
| 3 | UCL | 1 68 | 22 52 | 16 05 | 14 61 | 230 30 |
| 3 | UCF | 1 68 | 22 52 | 16 75 | 14 61 | 233 33 |
| 3 | POF | 1 68 | 5 95 | 2 93 | 2 67 | 53 94 |
| 4 | WAL | 2 04 | 18 54 | 12 70 | 11 56 | 187 50 |
| 4 | UCR | 2 04 | 31 22 | 22 02 | 20 04 | 316 18 |
| 4 | UCL | 2 04 | 33 17 | 23 71 | 21 59 | 338 24 |
| 4 | UCF | 1 02 | 20 49 | 13 55 | 11 56 | 194 85 |
| 4 | POF | 1 02 | 4 10 | 1 69 | 1 54 | 33 82 |
| 5 | WAL | 1 04 | 17 98 | 13 00 | 11 05 | 180 68 |
| 5 | UCR | 2 09 | 30 97 | 24 27 | 19 73 | 323 71 |
| 5 | UCL | 2 09 | 24 97 | 18 21 | 15 00 | 252 20 |
| 5 | UCF | 2 09 | 28 97 | 21 67 | 18 15 | 297 37 |
| 5 | POF | 1 04 | 5 39 | 2 86 | 2 37 | 47 80 |
| 6 | WAL | 1 89 | 16 23 | 12 52 | 9 97 | 169 88 |
| 6 | UCR | 1 89 | 20 74 | 15 65 | 12 82 | 214 04 |
| 6 | UCL | 1 89 | 21 64 | 16 43 | 13 54 | 224 24 |
| 6 | UCF | 0 94 | 19 84 | 14 08 | 11 40 | 193 66 |

| Table B4 Solvent concentrations | | | | | | |
|---|---|---|---|---|---|---|
| Run | Location | Ethyl acetate (ppm) | Toluene (ppm) | Xylenes (ppm) | n-Butyl acetate (ppm) | Combined solvent concentration ($mg/m^3$) |
| 6 | POF | 0 94 | 5 05 | 2 82 | 2 14 | 44 85 |
| 7 | WAL | 1 65 | 20 54 | 15 08 | 12 48 | 208 33 |
| 7 | UCR | 0 83 | 22 12 | 19 19 | 14 98 | 241 07 |
| 7 | UCL | 1 65 | 21 33 | 16 45 | 13 11 | 220 24 |
| 7 | UCF | < 1 8 | < 1 8 | < 1 7 | < 1 6 | 0 00, dropped from analysis |
| 7 | POF | 10 74 | 15 80 | 4 46 | 4 12 | 137 20 |
| 8 | WAL | 1 93 | 11 98 | 7 68 | 6 33 | 115 63 |
| 8 | UCR | 1 93 | 27 64 | 19 99 | 17 47 | 281 25 |
| 8 | UCL | 1 93 | 32 25 | 23 19 | 19 66 | 322 92 |
| 8 | UCF | 1 93 | 25 80 | 16 79 | 14 56 | 246 53 |
| 8 | POF | 0 96 | 4 24 | 1 60 | 1 46 | 33 33 |
| 9 | WAL | 1 96 | 18 73 | 14 63 | 11 84 | 197 65 |
| 9 | UCR | 1 96 | 29 97 | 23 57 | 19 98 | 317 65 |
| 9 | UCL | 1 96 | 39 34 | 31 70 | 25 90 | 416 47 |
| 9 | UCF | 1 96 | 26 23 | 17 88 | 15 54 | 257 65 |
| 9 | POF | 0 98 | 3 84 | 1 63 | 1 48 | 32 12 |
| 10 | WAL | 3 02 | 28 88 | 20 05 | 19 02 | 297 46 |
| 10 | UCR | 2 01 | 27 92 | 21 72 | 20 54 | 304 72 |
| 10 | UCL | 3 02 | 48 14 | 36 76 | 34 99 | 518 74 |
| 10 | UCF | 3 02 | 36 58 | 25 06 | 24 34 | 373 64 |
| 10 | POF | 3 02 | 6 26 | 2 51 | 2 28 | 56 23 |
| 11 | WAL | 3 06 | 26 38 | 18 65 | 15 44 | 265 03 |
| 11 | UCR | 2 04 | 24 42 | 18 65 | 16 21 | 257 67 |
| 11 | UCL | 2 04 | 40 05 | 36 45 | 30 10 | 460 12 |
| 11 | UCF | 2 04 | 27 35 | 20 35 | 17 75 | 283 44 |
| 11 | POF | 18 39 | 18 56 | 4 24 | 3 78 | 172 64 |
| 12 | WAL | 2 02 | 18 38 | 11 75 | 9 94 | 174 97 |

Abbreviations UCL - under car left, UCR - under car right, W - wall, POF - personal sample , UCF - under car left side, filtered inlet

| Table B4 Solvent concentrations | | | | | | |
|---|---|---|---|---|---|---|
| Run | Location | Ethyl acetate (ppm) | Toluene (ppm) | Xylenes (ppm) | n-Butyl acetate (ppm) | Combined solvent concentration ($mg/m^3$) |
| 12 | UCR | 2 02 | 25 15 | 16 79 | 13 76 | 240 58 |
| 12 | UCL | 2 02 | 37 73 | 26 87 | 22 93 | 375 46 |
| 12 | UCF | 2 33 | 32 89 | 21 83 | 19 87 | 321 87 |
| 12 | POF | 2 02 | 3 97 | 1 68 | 1 53 | 36 82 |
| 13 | WAL | 2 08 | 26 84 | 18 98 | 16 49 | 269 66 |
| 13 | UCR | 2 08 | 36 78 | 28 47 | 23 56 | 382 02 |
| 13 | UCL | 2 08 | 30 81 | 23 29 | 21 99 | 329 59 |
| 13 | UCF | 3 12 | 34 79 | 25 02 | 23 56 | 363 30 |
| 13 | POF | 2 08 | 5 17 | 2 59 | 2 36 | 49 44 |
| 14 | WAL | 3 80 | 32 80 | 26 93 | 23 12 | 364 48 |
| 14 | UCR | 2 78 | 26 60 | 23 08 | 18 91 | 300 67 |
| 14 | UCL | 3 25 | 35 46 | 30 01 | 25 92 | 399 22 |
| 14 | UCF | 3 06 | 32 80 | 26 93 | 23 12 | 361 80 |
| 14 | POF | 2 78 | 7 18 | 3 69 | 3 08 | 67 82 |
| 15 | WAL | 4 49 | 25 34 | 25 05 | 21 14 | 321 22 |
| 15 | UCR | 3 90 | 20 41 | 20 16 | 17 24 | 260 74 |
| 15 | UCL | 5 67 | 34 49 | 34 21 | 28 92 | 436 87 |
| 15 | UCF | 5 67 | 33 79 | 33 60 | 27 81 | 426 26 |
| 15 | POF | 3 98 | 7 74 | 3 30 | 2 78 | 71 09 |
| 16 | WAL | 8 74 | 33 06 | 31 72 | 27 50 | 424 92 |
| 16 | UCR | 7 92 | 31 32 | 31 72 | 26 13 | 408 85 |
| 16 | UCL | 13 65 | 62 65 | 75 51 | 61 19 | 904 92 |
| 16 | UCF | 10 92 | 44 38 | 43 04 | 36 44 | 567 21 |
| 16 | POF | 1 82 | 4 70 | 2 57 | 2 06 | 45 25 |

Abbreviations UCL - under car left, UCR - under car right, W - wall, POF - personal sample , UCF - under car left side, filtered inlet

# Appendix C

Statistical analysis for the data collect
July 6-11, 1993

The objective of the statistical analysis was to determine if there is a difference between the two spray paint guns in the seven dependent variables listed in the following paragraphs This testing involved painting a car body with one of two types of spray-painting guns and one of two types of paints During each experimental run, air samples were collected at five locations This analysis was done for seven dependent variables These dependent variables were the combined solvent concentration, the combined solvent concentration/per mill of film thickness, the particulate overspray concentration, the particulate overspray concentration/mil of film thickness, the titanium concentration, the titanium concentration/mil of film thickness and the film thickness The analysis was performed on the natural logarithms of the concentrations and the concentrations/mil of film thickness This was done to achieve uniform variances and less departure from a normal distribution for the dependent variables involving concentration The dependant variable, film thickness, was not log-transformed The analysis assumed that ambient conditions for the experimental runs were randomly changing over the course of the study

ANALYSIS OF VARIANCE

A special analysis must be used because the measurements taken at the five locations for the same run are apt to be correlated because these measurements share the same test conditions as described in the preceding paragraph [1,2] The GUN and PAINT factors are termed "between run" factors Each experimental run involved a specific paint and spray-painting gun Variability between runs are due to a number of factors which are constant within a run and may not be completely known to the investigators These factors may include the worker's practices during a specific run, variations in the paint being used, etc Some of the effects that are of interest are associated with differences that occur within a run, i e , LOCATION, or the variation of these with the between run factors

The repeated measures ANOVA is accomplished by putting the between run factors into the model first to remove their effects and obtain their mean squares for these sources of variation GUN, PAINT, and GUN*PAINT Then, the remaining sum of squares is used to compute the mean square for run is computed The mean square for run literally is the run to run variability in this experiment that can not be attributed to gun and/or paint If the mean squares for the variables GUN, PAINT and GUN*PAINT are larger than the mean square for run, they are said to affect the dependent variable

The "within run" analysis is performed next The factors for this are the interactions of the between run factors with LOCATION The main effect of LOCATION can be considered the GRAND-MEAN*LOCATION interaction The other effects entered then are the GUN*LOCATION, PAINT*LOCATION, GUN*PAINT*LOCATION, and LOCATION*RUN, which is obtained as a residual The last term is used to obtain the variability at each sampling location caused by measurement variability and other uncontrolled factors This variability term is used to evaluate whether the variables, GUN*LOCATION, PAINT*LOCATION, and GUN*PAINT*LOCATION, affected the dependent variables

These analyses were accomplished by using SAS's General Linear Models Procedure (PROC GLM) [3] The independent variables were entered in the order shown in Item 1 of Figure C1 (Although, if the design is not balanced, PAINT - which is a nuisance factor - was entered first and its effects removed before GUN is entered) The Type I sum of squares and mean squares were used to conduct the analysis of variance As shown in Items 2 and 3, hypothesis testing was customized by using the TEST statement and using the appropriate error term in each case

The analysis of variance results are summarized in Table C1 Statistical significance at the 0 05 level was required to reject a null hypothesis of no effect for any independent variable in the analysis Spray-painting gun and sampling location significantly affected the particulate overspray concentration and the ratio of particulate overspray concentration to film thickness In Table C1, spray painting gun did not significantly affect the titanium or combined solvent concentrations/mil of film thickness However, the interaction between sampling location and spray painting gun significantly affected the combined solvent concentration and the ratio of combined solvent concentration to film thickness This indicates that, at least one sampling location, gun affected the observed difference in the combined solvent concentration The following section describes further investigation of this gun-location interaction The results presented in Table C1 indicate that gun did not affect the titanium concentration or the titanium concentration/mill of paint film thickness The last section of this attachment presents a reason for this result

A multiple comparison test, Tukey (HSD), was used to explore how air contaminant concentrations varied within guns or sampling location Multiple comparison tests for the effect of sampling location upon the particulate overspray concentration and the combined solvent concentration are presented in Table C2 and Figure C2

Evaluation of the gun - location interaction for the combined solvent concentrations

The objective was to account for a statistically significant (spray) gun by location interaction for the logarithmically transformed solvent variables detected in the initial analysis The initial analysis examined the "main" effects of GUN, PAINT, and LOCATION, respectively, and each set of interactions using PROC GLM There were no statistically significant

Dependent Variable. LTOTSOLV

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 78 | 50 71029486 | 0.65013199 | | |
| Error | 0 | | | | |
| Corrected Total | 78 | 50 71029486 | | | |

| R-Square | C.V. | Root MSE | LTOTSOLV Mean |
|---|---|---|---|
| 1 000000 | 0 | 0 | 5.28563917 |

Item 1

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| GUN | 1 | 0.15193409 | 0.15193409 | | . |
| PAINT | 1 | 0.00352060 | 0 00352060 | | . |
| GUN*PAINT | 1 | 0 22633528 | 0 22633528 | | . |
| RUN | 12 | 4 67351620 | 0 38945968 | . | . |
| LOC | 4 | 38.72893722 | 9 68223430 | | |
| GUN*LOC | 4 | 2 09645602 | 0 52411400 | . | |
| PAINT*LOC | 4 | 0 59661318 | 0 14915330 | | . |
| GUN*PAINT*LOC | 4 | 0 55363250 | 0 13840812 | | . |
| LOC*RUN | 47 | 3 67934977 | 0.07828404 | | . |

Item 2

Tests of Hypotheses using the Type I MS for RUN as an error term

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| GUN | 1 | 0.15193409 | 0 15193409 | 0 39 | 0.5439 |
| PAINT | 1 | 0.00352060 | 0 00352060 | 0 01 | 0.9258 |
| GUN*PAINT | 1 | 0 22633528 | 0 22633528 | 0 58 | 0 4606 |

Item 3

Tests of Hypotheses using the Type I MS for LOC*RUN as an error term

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| LOC | 4 | 38 72893722 | 9 68223430 | 123.68 | 0 0001 |
| GUN*LOC | 4 | 2 09645602 | 0 52411400 | 6 70 | 0.0002 |
| PAINT*LOC | 4 | 0.59661318 | 0 14915330 | 1 91 | 0.1252 |
| GUN*PAINT*LOC | 4 | 0 55363250 | 0 13840812 | 1 77 | 0.1511 |

Authors annotation. The variable "GUN" describes the type of gun which was used, an HVLP spray painting gun or a conventional Painting gun. The variable "Paint" describes whether paint A or B was used during this experimental run The variable "LOC" describes the sampling location for the data.

Figure C1 An example of a repeated measures analysis of variance using the SAS General Linear Models Procedure

Results of the repeated measures anova used to evaluate whether spray painting gun, sampling location, and paint affected the dependent variables

| Independent variables | Probability of a larger F, the probability that chance caused the observed differences in the dependent variables | | | | | | |
|---|---|---|---|---|---|---|---|
| | Film thickness | Combined solvent concentration | Combined solvent concentration/ film thickness | Particulate Overspray concentration | Particulate Overspray Concentrati on divided by film thickness | Titanium Concentration | Titanium Concentration divided by film thickness |
| paint | 0 22 | 0 92 | 0 4639 | 9924 | 0 6126 | 0 6769 | 0 5468 |
| gun | 0 13 | 0 54 | 0 1813 | 0 0012 | 0 0009 | 0 1589 | 0 098 |
| gun*paint | 0 0078 | 0 46 | 0 5299 | 0 51 | 0 5552 | 0 9181 | 0 783 |
| location | 0 0001 | 0 0001 | 0 0001 | 0 0001 | 0 0001 | 0 0001 | 0 0001 |
| gun*location | 0 348 | 0 0002 | 0 0002 | 0 5734 | 0 5734 | 0 6165 | 0 6165 |
| paint*location | 0 8547 | 0 1252 | 0 125 | 0 6334 | 0 6334 | 0 4472 | 0 4472 |
| gun*paint* location | 0 5374 | 0 1511 | 0 1511 | 0 4501 | 0 4501 | 0 646 | 0 6460 |

Table C2 Multiple Comparison Test Results Showing the Effect of Sampling Location upon Geometric Mean Total Dust Concentration

| Sampling location code | Geometric mean ($mg/m^3$) | N | Tukey grouping (geometric means with different letters differ significantly ) |
|---|---|---|---|
| UCL (under car left side) | 32 | 16 | A |
| UCR (under car, right side) | 19 | 16 | A,B |
| Wal (near wall) | 17 | 16 | B |
| Personal sample, closed face | 1 9 | 16 | C |
| Personal sample, open faced | 1 8 | 16 | C |

differences for either dependent variable associated with PAINT or its interactions with the other factors  The GUN difference was not statistically significant for either variable but LOCATION differences and the GUN-LOCATION interactions were for both dependent variables

A special analysis was conducted to identify specific differences in the performance of the two spray guns among the five locations that was indicated by the presence of a GUN-LOCATION interaction  There cannot be a real GUN-LOCATION interaction unless there is a real gun difference at least at one location  The presence of the interaction, however, indicates that the "main" effect of GUN is merely an average of the specific GUN differences at the five locations that paint were applied and is not a useful source of information

General Linear Models Procedure
Tukey's Studentized Range (HSD) Test for variable: LTOTSOLV
NOTE: This test controls the type I experimentwise error rate
Alpha= 0.05 Confidence= 0.95 df= 47 MSE= 0.078284
Critical Value of Studentized Range= 4.011

Comparisons significant at the 0.05 level are indicated by '***'

| LOC Comparison | Simultaneous Lower Confidence Limit | Difference Between Means | Simultaneous Upper Confidence Limit | |
|---|---|---|---|---|
| UCL - UCR | -0.1596 | 0.1210 | 0.4016 | |
| UCL - UCF | -0.0996 | 0.1856 | 0.4708 | |
| UCL - WAL | 0.2342 | 0.5148 | 0.7954 | *** |
| UCL - POF | 1.6134 | 1.8940 | 2.1746 | *** |
| UCR - UCL | -0.4016 | -0.1210 | 0.1596 | |
| UCR - UCF | -0.2206 | 0.0646 | 0.3498 | |
| UCR - WAL | 0.1132 | 0.3938 | 0.6743 | *** |
| UCR - POF | 1.4924 | 1.7730 | 2.0536 | *** |
| UCF - UCL | -0.4708 | -0.1856 | 0.0996 | |
| UCF - UCR | -0.3498 | -0.0646 | 0.2206 | |
| UCF - WAL | 0.0439 | 0.3292 | 0.6144 | *** |
| UCF - POF | 1.4232 | 1.7084 | 1.9937 | *** |
| WAL - UCL | -0.7954 | -0.5148 | -0.2342 | *** |
| WAL - UCR | -0.6743 | -0.3938 | -0.1132 | *** |
| WAL - UCF | -0.6144 | -0.3292 | -0.0439 | *** |
| WAL - POF | 1.0987 | 1.3793 | 1.6599 | *** |
| POF - UCL | -2.1746 | -1.8940 | -1.6134 | *** |
| POF - UCR | -2.0536 | -1.7730 | -1.4924 | *** |
| POF - UCF | -1.9937 | -1.7084 | -1.4232 | *** |
| POF - WAL | -1.6599 | -1.3793 | -1.0987 | *** |

Authors annotation: The dependent variable is the natural logarithm of the combined solvent concentration. This test computes the difference between the combined solvent concentrations at all of the different sampling locations. The codes for the sampling location are given in Appendix B

Figure C2. Multiple comparison test conducted to evaluate how the combined solvent concentration varied among the sampling locations

The analysis simultaneously examined all of the GUN contrasts at the five locations, in this case the simple gun differences at the five locations, to determine how many, if any, can be inferred to be real, or if one or more contrasts of such differences across locations appears to be non-zero, or if there is some pattern across locations for the size of the gun differences There are five degrees of freedom for this set of contrasts, one for each location-specific gun difference A Scheffe' or "S-method" multiple comparison analysis over this five degrees of freedom "space" would seem useful for this However, the five gun differences are not statistically independent and linear combinations which do not involve contrasts across locations involve both the between "automobile" and the within "automobile" components of variance while contrasts across locations involve only the latter component

The Scheffe' S-method procedure was used to examine contrasts of the gun differences across locations, which are the contrasts associated with the interaction sum of squares found significant in the initial analysis By the statistical model used, these contrasts do not involve the error factors associated with automobiles, only specific locations However, instead of treating this space of contrasts as having four degrees of freedom, which would ordinarily be done, it is assigned five degrees of freedom for the entire set of interest Thus, any sum of squares is divided by five, not four, and the F-ratio is treated as having five degrees of freedom for the numerator

After inspecting the estimates, seven location contrasts of the GUN difference were analyzed The gun difference found for the personal sample was contrasted with each of the locations on the autobody and the wall, the average of the latter, and the average of those only on the autobody Additionally, the gun difference found on the wall was contrasted with the average of those on the autobody Different SAS PROC GLM "computer runs" were used to obtain estimates of these contrasts, the proper standard deviation estimates, and the proper coefficients of the estimated standard deviation to obtain estimates of their standard errors The correct standard deviation to be used as the factor to obtain the correct standard errors was the square root of the "location x run" mean square error A Student t-ratios of the contrasts previously described were then obtained by dividing each contrast estimate by its estimated standard error This was squared and divided by 5 to obtain the required F-ratios with 5 and 47 df

SAS PROC GLM was then used to obtain estimates of the location-specific GUN differences A separate "computer run," based on the statistical model, was used to estimate both the "between experimental runs," also termed "all," and "within experimental runs," i e , "location" variance components A linear combination of these was used to obtain the variance estimate required to estimate the standard errors of the five location-specific gun difference estimates However, when the square root of this quantity was compared to the square root of a SAS PROC GLM computer run which ignored the repeated measures structure of the experimental design, there was no difference to two decimal places Nevertheless, the corrected standard errors were used

However, the F-ratios used to test the null hypothesis of no difference between gun at each location were computed by squaring the ratio of the estimated difference to the estimated standard error of that estimate and then dividing by five  The resulting F-ratios were treated as having 5 and 33 5 df (using Sattherwaite's approximation)

RESULTS

The results of the analysis of the contrasts involving the gun differences specific to each of the five locations are shown in the following table  The error type corresponds to the sources of error described above  "ALL" refers to both between and within autobody run sources while "WITHIN" refers only to the latter

| Dependent Variable LTOTSOLV (the natural logarithm of the combined solvent concentration) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Contrast[1] | Error Type | Estimate | Incorrect Std Error | Correction Factor | Corrected Std Error | F-Ratio | df | Significance Level |
| GUN DIFF POF | ALL | 0 65 | 0 1876 | 0 9991 | 0 1874 | 2 38 | 5,33 5 | 0 059 |
| GUN DIFF UCF | ALL | -0 09 | 0 1953 | 0 9991 | 0 1951 | 0 05 | 5,33 5 | 0 999 |
| GUN DIFF UCL | ALL | -0 15 | 0 1876 | 0 9991 | 0 1874 | 0 13 | 5,33 5 | 0 983 |
| GUN DIFF UCR | ALL | -0 19 | 0 1876 | 0 9991 | 0 1874 | 0 22 | 5,33 5 | 0 953 |
| GUN DIFF WAL | ALL | 0 28 | 0 1876 | 0 9991 | 0 1874 | 0 46 | 5,33 5 | 0 805 |
| GUN DIFF AVGU | ALL | -0 15 | 0 1098 | 0 9991 | 0 1097 | 0 36 | 5 33 5 | 0 870 |
| GUN D (POF-UCF) | WITHIN | 0 74 | 0 2708 | 0 7457 | 0 2019 | 2 70 | 5,47 | 0 032 |
| GUN D (POF-UCL) | WITHIN | 0 80 | 0 2653 | 0 7457 | 0 1978 | 3 28 | 5,47 | 0 013 |
| GUN D (POF-UCR) | WITHIN | 0 84 | 0 2653 | 0 7457 | 0 1978 | 3 62 | 5,47 | 0 008 |
| GUN D (POF-WAL) | WITHIN | 0 36 | 0 2653 | 0 7457 | 0 1978 | 0 67 | 5,47 | 0 645 |
| GUN D (POF-AVGNP) | WITHIN | 0 69 | 0 2102 | 0 7457 | 0 1567 | 3 84 | 5,47 | 0 005 |
| GUN D (POF-AVGU) | WITHIN | 0 79 | 0 2174 | 0 7457 | 0 1621 | 4 81 | 5,47 | 0 001 |
| GUN D (WAL-AVGU) | WITHIN | 0 43 | 0 2174 | 0 7457 | 0 1621 | 1 42 | 5,47 | 0 236 |

1 Abbreviations

POF personal sample
WAL on the wall
UCF under the car, left-side filtered
UCL under car, left side
UCR under car, right side
OTW off the wall
AVGNP average of all except personal
AVGU average of under the car
D or DIFF difference

Dependent Variable LTS_THIC (natural logarithm of the combined solvent concentration divided by film thickness)

| Contrast[1] | Error type | Estimate | Incorrect std error | Correction factor | Corrected std error | F-Ratio | df | Significance level |
|---|---|---|---|---|---|---|---|---|
| GUN DIFF POF | ALL | 0 75 | 0 1857 | 1 0019 | 0 1861 | 3 27 | 5,33 5 | 0 016 |
| GUN DIFF UCF | ALL | 0 02 | 0 1933 | 1 0019 | 0 1937 | 0 00 | 5,33 5 | 1 000 |
| GUN DIFF UCL | ALL | -0 05 | 0 1857 | 1 0019 | 0 1861 | 0 01 | 5,33 5 | 1 000 |
| GUN DIFF UCR | ALL | -0 09 | 0 1857 | 1 0019 | 0 1861 | 0 05 | 5,33 5 | 0 999 |
| GUN DIFF WAL | ALL | 0 39 | 0 1857 | 1 0019 | 0 1861 | 0 88 | 5,33 5 | 0 508 |
| GUN DIFF AVGU | ALL | -0 04 | 0 1087 | 1 0019 | 0 1089 | 0 02 | 5,33 5 | 1 000 |
| GUN D (POF- UCF) | WITHIN | 0 73 | 0 2681 | 0 7532 | 0 2019 | 2 62 | 5,47 | 0 036 |
| GUN D (POF- UCL) | WITHIN | 0 80 | 0 2627 | 0 7532 | 0 1978 | 3 28 | 5,47 | 0 013 |
| GUN D (POF- UCR) | WITHIN | 0 84 | 0 2627 | 0 7532 | 0 1978 | 3 62 | 5,47 | 0 008 |
| GUN D (POF- WAL) | WITHIN | 0 36 | 0 2627 | 0 7532 | 0 1978 | 0 67 | 5,47 | 0 645 |
| GUN D (POF- AVGNP) | WITHIN | 0 68 | 0 2081 | 0 7532 | 0 1567 | 3 81 | 5,47 | 0 006 |
| GUN D (POF- AVGU) | WITHIN | 0 79 | 0 2152 | 0 7532 | 0 1621 | 4 76 | 5,47 | 0 001 |
| GUN D (WAL- AVGU) | WITHIN | 0 43 | 0 2152 | 0 7532 | 0 1621 | 1 39 | 5,47 | 0 245 |

The results for the two dependent variables are virtually identical The location-specific analyses, e g , those for the simple gun difference or the average of these across specified locations, also indicate that there is about 95 percent confidence that there is a gun difference at the POF location No such conclusion can be made at any other location

The gun difference for the personal sample differs statistically significantly from the gun differences at all three "under the car" locations and the average of these but not from the gun difference at the wall location The gun difference for personal sample also differs statistically significantly from the average of the other four locations The gun difference estimate is the second in size after that for the personal sample However, the difference between that difference and the average gun difference for the three "under the car" locations is not statistically significant

INTERPRETATION

These results indicate that differences in performance between the two guns for these dependent variables were detected in the personal sample but at no other location Any such difference at the wall or at any under the car location, if any indeed, were too small to be detected with this study

Moreover, whatever differences in performance of the two guns there were at the five locations, the one for the personal sample is larger in absolute size than at any of the under the car locations Any other differences among the locations were too small to be detected with this study, if indeed any such existed

Titanium Concentration Measurements

Because the titanium content of the paint is expected to be constant, the titanium air sampling results should be similar to the particulate overspray concentration results Thus, one would expect spray painting gun to significantly affect titanium concentration However, the variability in the titanium data appeared to be much larger than the variability in the particulate overspray concentration data The means squares for run, respectively, were 5 4 and 0 43 (both with 12 degrees of freedom) Unfortunately, the titanium content of particulate overspray was not constant The logarithm of the ratio of micrograms of titanium to the milligrams of total dust collected on each air samples was found to be significantly affected by both location (Prob > F = 0 03) and individual run (Prob > F = 0 0002) Apparently, the titanium content of the paint aerosol was not constant This suggests that the titanium content of the paint was not constant This probably is responsible for the drastic increase in the variability of the titanium concentration measurements Thus, the titanium data is not believed to be useful for evaluating whether the choice of the spray painting gun affects air contamination in a spray-painting booth The painter indicated that the paint was blended by a local supplier The blender mixes several tints to obtain a consistent color, there is no effort to control the titanium content

General Linear Models Procedure

Dependent Variable LRT_TM

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 19 | 153 1187622 | 8 0588822 | 3.44 | 0 0001 |
| Error | 60 | 140.6948297 | 2 3449138 | | |
| Corrected Total | 79 | 293.8135919 | | | |

| R-Square | C V | Root MSE | LRT_TM Mean |
|---|---|---|---|
| 0.521143 | 42.77048 | 1.531311 | 3.58029901 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| LOCATION | 4 | 26.3261236 | 6 5815309 | 2.81 | 0 0334 |
| RUN | 15 | 126 7926386 | 8 4528426 | 3.60 | 0 0002 |

Authors annotation· The dependent variable is the natural logarithm of the mass of titanium collected on the air sample divided by the mass of particulate matter collected on the filter

Figure C3 Use of SAS General Linear Models Procedure to evaluate whether the titanium content of the overspray is varying with run and sampling location

```
Tukey's Studentized Range (HSD) Test for variable: LRT_TM
         Alpha= 0.05  df= 60  MSE= 2.344914
     Critical Value of Studentized Range= 5 056
       Minimum Significant Difference= 3 4623
Means with the same letter are not significantly different

        Tukey Grouping              Mean       N   RUN
                     A              5 180      5   13.00
                     A
                     A              4.913      5   10.00
                     A
                     A              4 886      5   15 00
                     A
                     A              4 835      5   14.00
                     A
                     A              4 686      5   12.00
                     A
                     A              4 494      5   7.00
                     A
                     A              4 223      5   11.00
                     A
             B       A              4 078      5   9 00
             B       A
             B       A              3 748      5   5 00
             B       A
             B       A              2.903      5   4.00
             B       A
             B       A              2 808      5   8 00
             B       A
             B       A              2 805      5   3 00
             B       A
             B       A              2 698      5   2 00
             B       A
             B       A              2.242      5   6.00
             B       A
             B       A              2 169      5   16 00
             B
             B                      0.617      5   1 00

Tukey's Studentized Range (HSD) Test for variable  LRT_TM
         Alpha= 0 05  df= 60  MSE= 2 344914
     Critical Value of Studentized Range= 3.977
       Minimum Significant Difference= 1 5227

Means with the same letter are not significantly different

     Tukey Grouping              Mean       N   LOCATION

                  A              4 026      16  WAL
                  A
          B       A              3.940      16  UCR
          B       A
          B       A              3.890      16  UCL
          B       A
          B       A              3 571      16  PCF
          B
          B                      2 475      16  POF
```

Figure C4  Multiple comparison test results which explore how titanium content varies with sampling location and experimental run

## References


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3 SAS Institute [1988] SAS/STAT User's Guide, Release 6 03 Edition Box 800,0 Cary, North Carolina