IN-DEPTH STUDY REPORT:

CONTROL TECHNOLOGY FOR AUTOBODY REPAIR SHOPS: SMALL PARTS PAINTING IN A DOWNDRAFT BOOTH

at

BASF Corporation
Whitehouse, Ohio

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ABSTRACT

In prior studies, spray painting autobody parts in a downdraft booth had caused total paint mist concentrations to exceed 10 mg/m^3 when the parts were suspended from the ceiling of the booth This study was conducted to evaluate whether paint overspray exposures could be minimized by orienting the parts to be painted In this study, the effect of part orientation upon paint mist concentrations was studied in a downdraft spray painting booth The booth had an exhaust trench along the center axis of the booth Two parts were repeatedly painted a fender and a bumper The parts were set on saw horses on top of this exhaust trench The parts were oriented so that the part was either parallel or perpendicular to this exhaust trench When the bumper was perpendicular to the exhaust trench, the geometric mean total paint mist concentration increased from 5 5 to 15 mg/m^3 (p=0 007) This increased exposure may be due to an eddy located under cornices on the side of the booth When paint overspray is directed into these eddies, the eddy transports the paint overspray to the top of booth, resulting in the contamination of the incoming fresh air Computer modeling suggests that these eddies can be eliminated by altering the configuration of the booth

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a federal agency located in the Centers for Disease Control and Prevention under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct research and education programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential biological, chemical, and physical hazards.

The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects relevant to the control of hazards in the workplace. Since 1976, the ECTB has assessed control technology found within selected industries or used for common industrial processes. The ECTB has also designed new control systems where current industry control technology was insufficient. The objective of these studies has been to document and evaluate effective control techniques (e.g., isolation or the use of local ventilation) that minimize risk of potential health hazards and to create an awareness of the usefulness and availability of effective hazard control measures.

One area identified for ECTB control studies is the control of paint overspray at autobody repair shops. Workers who spray paint cars apply a clear coat which contains polyols and hardeners that are prepolymerized forms of diisocyanates. Generally, these polyisocyanates are trimers of hexamethylene diisocyanate (HDI). Exposure to these polyisocyanates can cause skin and eye irritation, respiratory sensitization, asthma, and reduced lung function.[1] Exposure limits for these polyisocyanates have not been addressed by Occupational Safety and Health Administration Permissible Exposure Limits (PELs), American Conference of Governmental Industrial Hygienist's Threshold Limit Values (TLVs), or recommended exposure limits (RELs) developed by the National Institute for Occupational Safety and Health. Because of the reported health effects and the number of painters seeking medical attention, the State of Oregon promulgated permissible exposure limits for HDI-based polyisocyanates. This Oregon PEL includes an 8-hour time-weighted average of 0.5 mg/m^3 and a short-term exposure limit of 1 mg/m^3.[2] This exposure limit is consistent with the exposure recommendations developed by a manufacturer of the HDI polyisocyanates.[3] Between 1980 and 1990, two-thirds of the personal air samples for HDI polyisocyanates exceeded the Oregon STEL with a geometric mean of 1.6 mg/m^3.[4]

During spray painting in autobody repair shops, workers are exposed to all of the paint components which are atomized. In addition to polyisocyanates, these constituents include organic solvents, metals such as lead and chromium, and trace quantities of HDI monomer. In a series of field evaluations of spray painting booths in the autobody repair industry, these exposures were generally found to be below exposure limits recommended by NIOSH, ACGIH, and OSHA.[5,6,7,8,9,10] However, in some shops, worker exposure to chromium did exceed the NIOSH REL for hexavalent chromium, and the available material safety data sheets did indicate that the chromium compound had a valance of +6 The NIOSH REL for hexavalent chromium is 1 $\mu g/m^3$

A study of control measures for paint overspray in autobody repair shops found that the type of spray painting booth and the choice of spray painting gun can be used to minimize worker exposure to paint overspray [11] Three types of spray painting booths are used in the autobody repair industry These are downdraft booths, semi-downdraft booths, and crossdraft booths The concept and operation of these booths are discussed in Figure 1 Previously reported measurements found that exposures to paint overspray in downdraft booths are lower than in the other two types of booths [11] In a downdraft booth, the paint overspray was dispersed without flowing back into the worker's breathing zone In a crossdraft booth and in semi-downdraft booths, the paint overspray is dispersed into the incoming fresh air, causing the worker's exposure to be elevated As a result, geometric mean particulate overspray concentrations were 1 9 and 2 7 mg/m^3 at two different downdraft booths versus 23 mg/m^3 at a crossdraft booth

HVLP spray painting guns are more efficient than conventional spray painting guns This caused total paint mist concentrations to be reduced by a factor of 2, and spray painting gun efficiency appeared to increase by 30 percent [12] As spray painting gun efficiency increases, the painter uses less paint and there is a more than proportionate decrease in worker exposure to particulate paint overspray Paint overspray is the paint which does not get deposited on the part, causing worker exposure to paint mist

During spray painting, painters are frequently exposed to excessive polyisocyanate concentrations [4] In addition, respirators are used incorrectly in this industry according to several surveys [11] Due to concern mainly for worker health risks, the Environmental Protection Agency's New Chemicals Program has been regulating polyisocyanate components of automotive refinishing paints and coatings for a number of years The end results have always been that regulation under the Toxic Substances Control Act essentially banned new polyisocyanates through strict regulation. Since automotive refinishing shops are generally small businesses with inadequate worker protection, an effort was made to address their exposure issues through a Product Stewardship Partnership The partnership is a voluntary program which includes members from the following federal government agencies and industries Environmental Protection Agency, Occupational Safety and Health Administration, National Institute for Occupational Safety and Health, National Paint and Coatings Association, National Automobile Dealers Association, Automotive Service Association, Automotive Service Industry Association, Collision Industry Conference, National Institute for Automotive Service Excellence, Inter-Industry Conference on Automotive Collision Repair, and individual paint manufacturers

An important element of this program is the development of a control strategy matrix describing the type of respiratory protection to be used with specific spray painting booths At one autobody repair shop, small parts were painted by suspending parts from the ceiling of a downdraft booth The painter pointed the spray painting gun toward the ceiling to paint the parts This resulted in

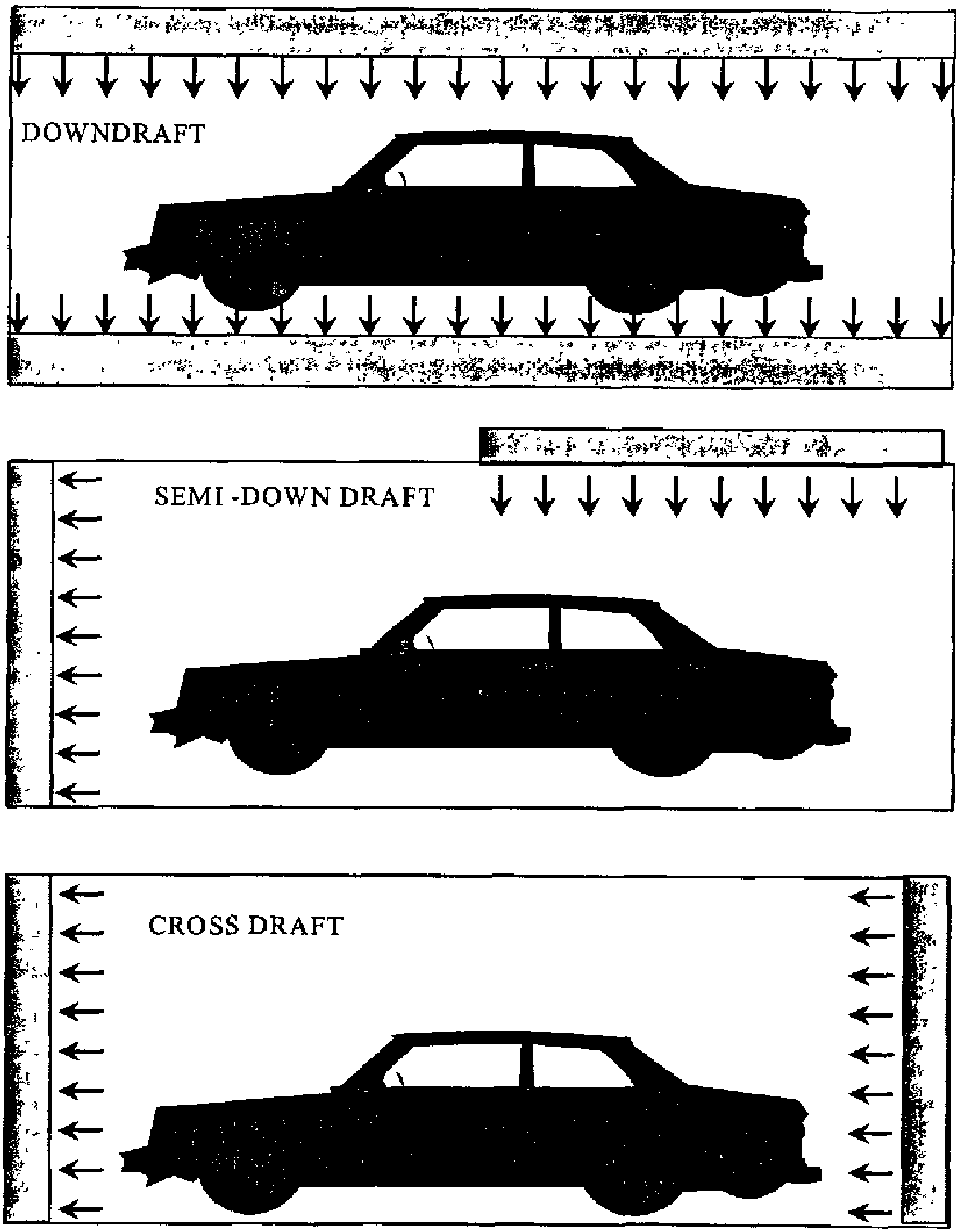

Figure 1 The three different styles of spray painting booths in the autobody repair industry

paint overspray concentrations which exceeded 10 mg/m^3 [6] Essentially, this worker's exposure to paint overspray was elevated because paint overspray was directed into the incoming fresh air In order to complete a matrix of control measures involving the type of spray painting booth, spray painting guns, and respirator, recommendations on the spray painting of parts was needed in downdraft booths Consequently, researchers from NIOSH and the BASF Federick G Weed Automotive Development Center collaborated to evaluate techniques for painting autobody parts in a downdraft spray painting booth

EXPERIMENTAL

The effect of parts orientation upon air contaminant exposure in a downdraft spray painting booth was studied Two types of parts were painted a fender and a bumper, as shown in Figures 2 and 3 The bumper was set horizontally on a saw horse The fender was mounted vertically on the saw horse The parts were oriented with respect to the exhaust trench which ran down the center of the booth These orientations are described schematically in Figure 4 and pictured in Figures 2 and 3 When the bumper is in the perpendicular orientation, it overhangs the exhaust trench in the floor of the booth The effect of part orientation upon the painter's air contaminant exposure and film thickness per mass of paint applied was experimentally studied These measurements were replicated three times for each orientation These orientations were run sequentially in an effort to find an orientation which minimized exposures The first orientation in Figure 4 was tried and the total mist concentrations appeared to be excessive As result, the two other orientations were tried In order to obtain an understanding of the role of airflow patterns and worker exposure, airflow patterns in the booth were evaluated experimentally by tracing airflow patterns and theoretically by estimating airflow patterns using computational fluid dynamics

The spray painting booth was a downdraft booth manufactured by DeVilbiss The booth dimensions are shown in Figure 5 Fresh air flows through filters located in the ceiling of the booth The air flows out of the booth through an exhaust trench located in the concrete floor of the booth The exhaust trench was covered with glass fiber paint arresting filters The painter used a high-volume, low-pressure spray painting gun (Sata Model NR95-HVLP Gravity Feed with a 1 3 tip, Spring Valley, Minnesota)

Air Contaminant Concentration Measurements

The following air contaminant concentrations were measured on the worker paint mist overspray concentration, organic solvent concentration, and hexamethylene diisocyanate trimer The latter were measured at the last two orientations described schematically in Figure 4 During each sampling session, four bumpers and fenders received two coats of paint However, only two bumpers and two fenders were painted at each time The time required for painting was recorded and used to compute the sample volume After the parts were painted, they were moved into an adjacent booth for curing at an elevated temperature These parts were repeatedly painted

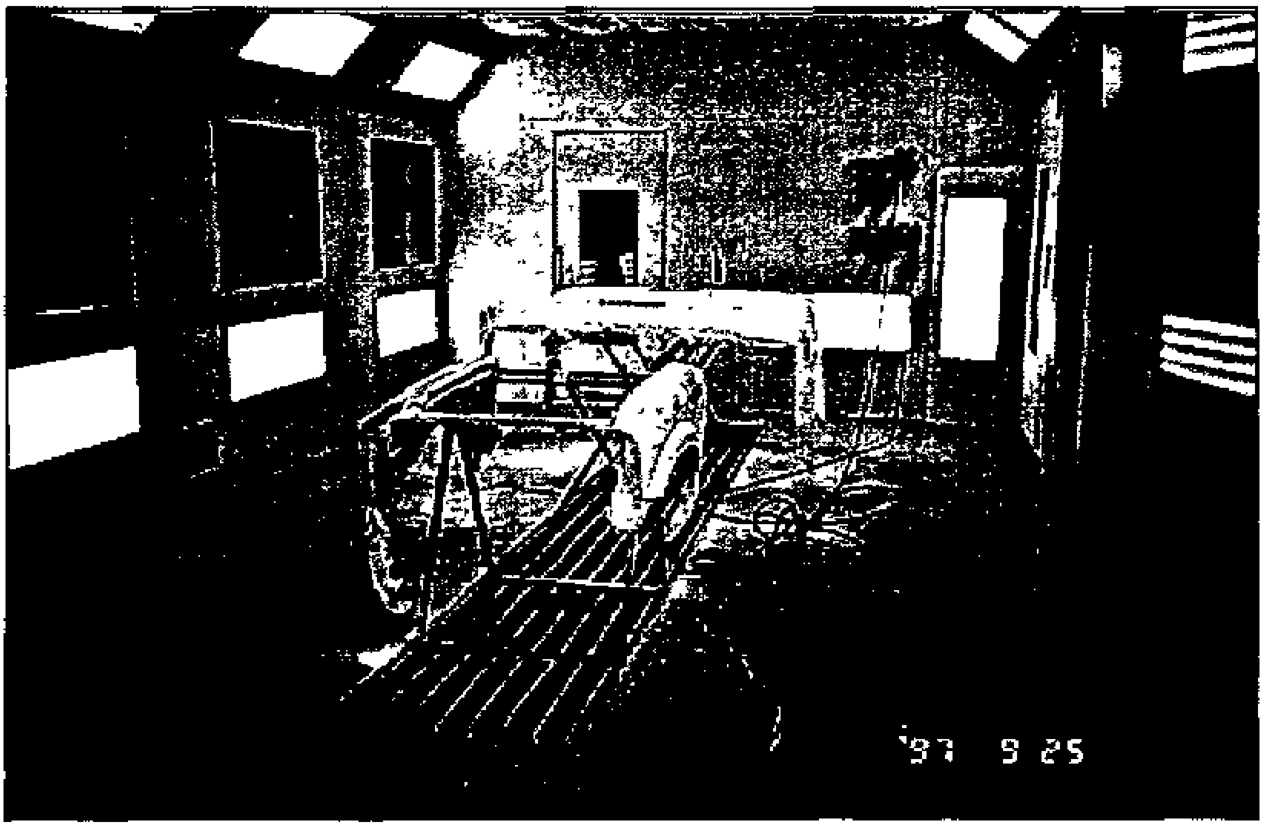

Figure 2 The fender is positioned so that it is parallel to the exhaust trench and the bumpers are across the exhaust trench

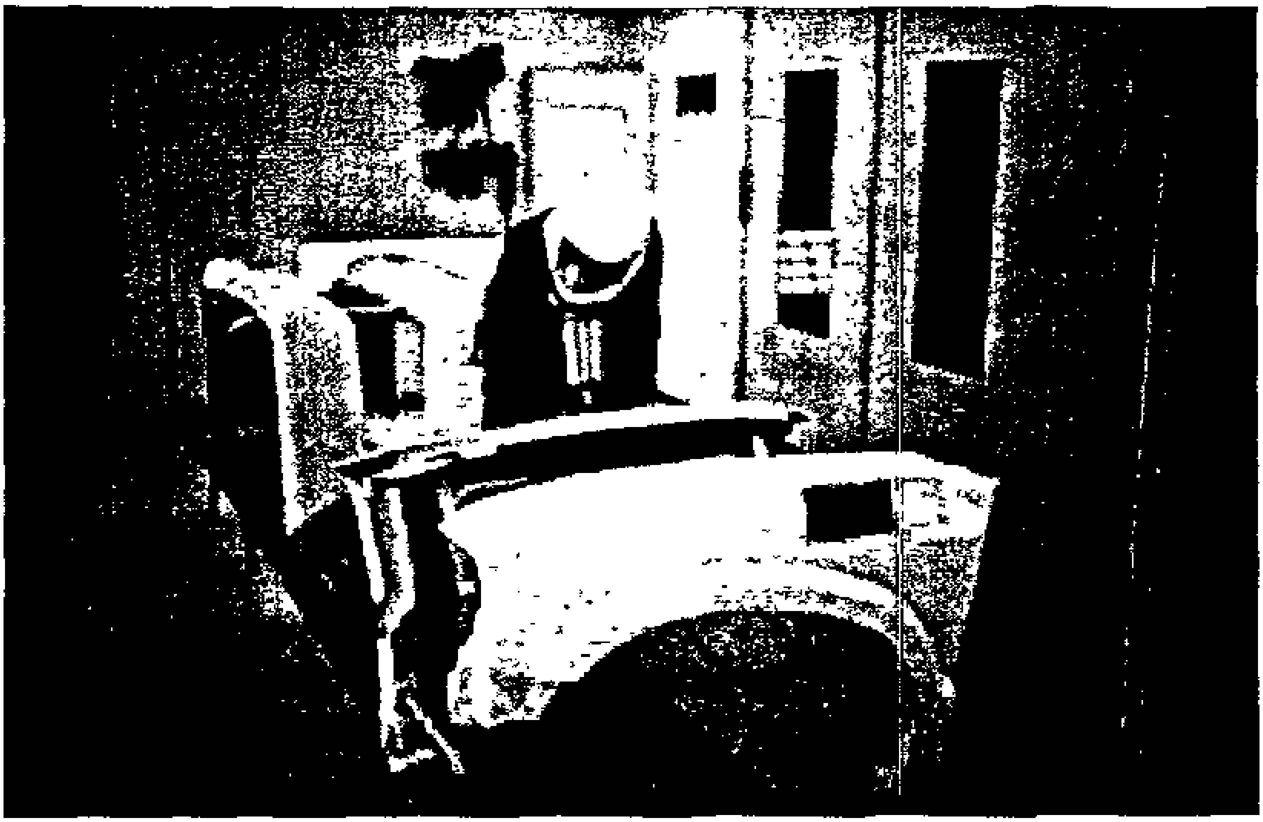

Figure 3 Fenders positioned so they are across the exhaust trench and the bumpers are positioned so they are perpendicular to the exhaust trench Note the presence of the test panel for film thickness measurement on the fender in the foreground of the picture

Orientation	
Fender	Bumper
parallel	Perpendicular
Perpendicular	parallel
parallel	parallel

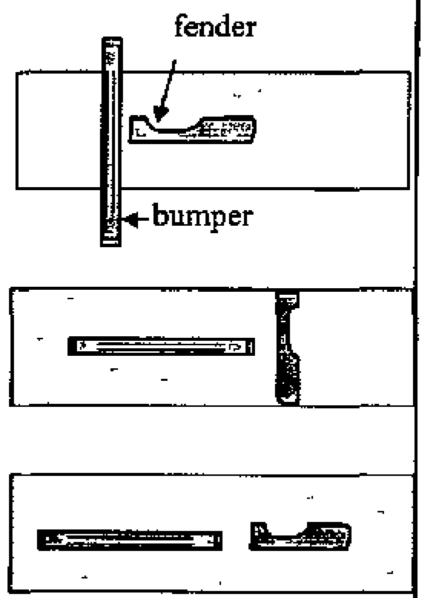

Figure 4 The orientation of bumper and fender with respect to the exhaust grate on the floor of the booth

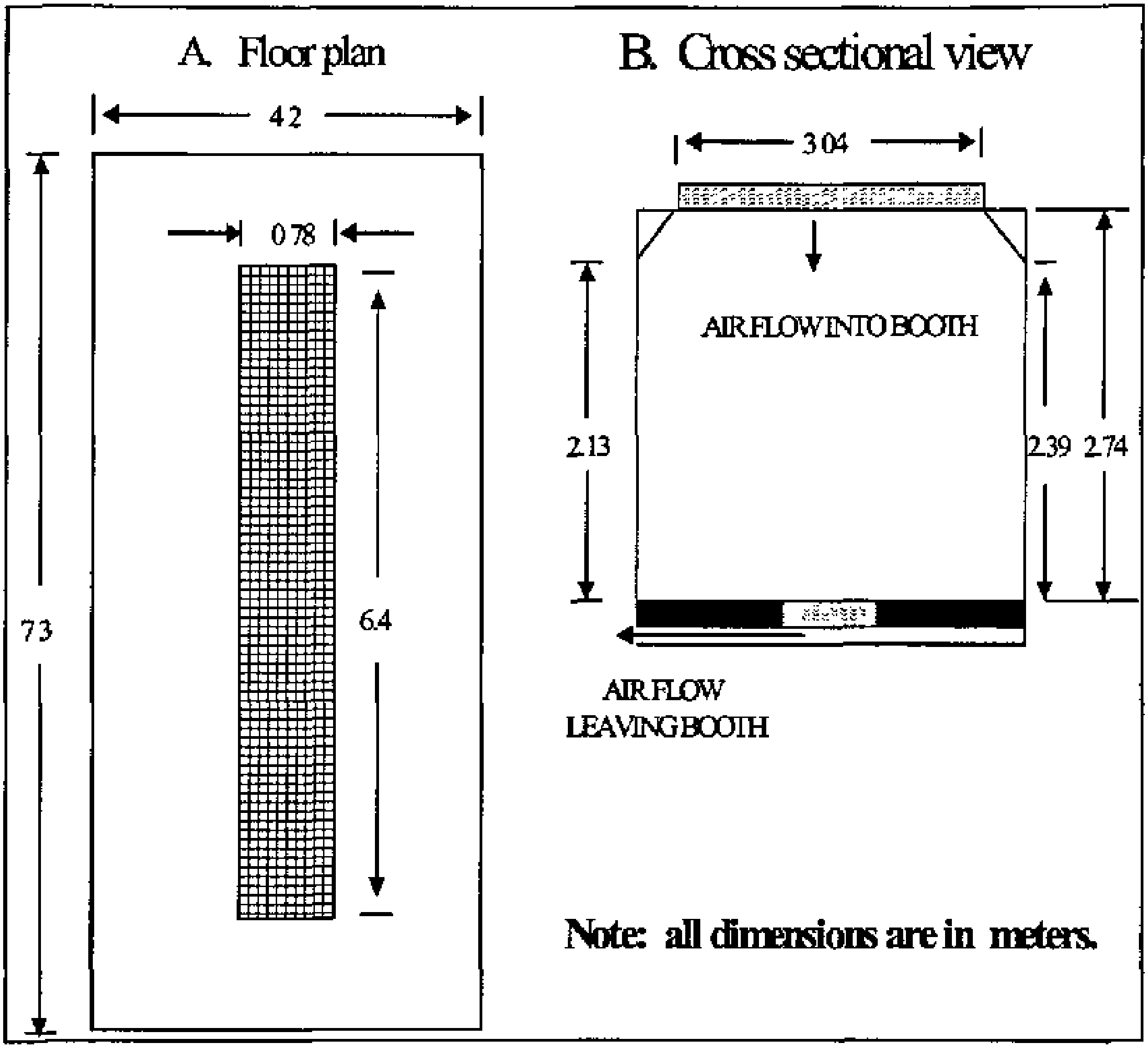

Figure 5 Schematic drawing of the spray painting booth

Total mist concentrations were measured by drawing a known volume of air through a preweighed, 37-mm filter mounted in a cassette Two different particulate overspray concentrations were measured on the painter open-face and closed-face samples The closed-face samples collected aerosol through a 4-mm diameter hole in the cassette's face cap The open-face samples were collected by removing the filter holder's face cap Sampling flow rates of 5 lpm were used The samples were analyzed as described in NIOSH Method 0500 [13]

Organic solvent concentrations (n-butyl acetate, total xylenes, toluene, and propylene glycol methyl acetate) were measured using NIOSH Methods 1450 and 1501 [14,15] The air samples were collected by drawing a known volume of air through a charcoal tube containing 100 mg and 50 mg of charcoal in the front and backup sections of the sorbent tube A sampling rate of 200 mL/minute was used The analytical method was used with these modifications

1 Desorption 30 minutes in 1 mL of carbon disulfide containing 1 µl/mL of benzene as an internal standard,

2 Gas Chromatograph Hewlett Packard Model 589A equipped with a flame ionization detector,

3 Column 30-m X 0 32-mm fused silica capillary coated internally with 0 5-µm of DBWAX,

4 Oven Conditions Temperature programming from 50 °C (held for 5 minutes) to 200 °C at a rate of 10 °C/minute, and

5 Media standards were used in the analysis

The hardener was a Hexamethylene Diisocyanate Trimer (HDT) The CAS number for this substance is 3779-63-3 According the material safety data sheet, the bulk sample of this resin was better than 99 percent HDT A method obtained from the Bayer Corporation was used to evaluate exposure to HDT [16] A known volume of air at a rate of 1 7 liters per minute was drawn through an impinger containing 15 mL of a 100 µm nitroreagent absorber solution The Bayer Method was used with these modifications·

1 Sample preparation Samples were dried under a gentle nitrogen stream at 45 °C and sonicated 20 minutes in 2 mL of acetonitrile then filtered,

2 Instrument HP1090 Autosampler, pump, and DAD detector,

3. Column Waters 4 6 X 150 mm Symmetry C18, 5 µm,

4 Column Temperature 40 °C,

5 Mobile phase 50/50 A/B to 25/75 in 6 minutes, linear program, hold 25/75 A/B for 5 minutes,

6 Flow rate 1 5 mL/Min,

7 Injection volume 40 µL; and,

8 Wavelength 275 and 254 nm

A cascade impactor (Anderson 2000 Incorporated) was used to measure the size distribution of the paint mist The impactor stages were loaded with preweighed glass fiber filters Air was drawn through the impactor at a flow rate of 15 1 lpm instead of the specified flow rate of 28 3 liters per minute As a result, the impaction velocity is reduced and the 50 percent cut diameter for each stage is increased The published cut diameters were increased by a factor of $(28\ 3/15\ 1)^{0\ 5}$ As long as the impactor jet's Reynolds number remains between 500 and 3000, the impactor's 50 percent cut diameter will be inversely proportional to the square root of the air velocity in the impaction jets [17] The impactor was placed under a fender which was being painted The impactor filters were pre- and post-weighed in a balance room after being allowed to equilibrate overnight Six filters were used as blanks The filters were weighed using a Mettler AE-163 balance The difference between the weight change of the filter and the average weight change of the six blanks was the mass of aerosol collected on the impaction stage

Ventilation Measurements and Analysis

The exhaust flow rate and the airflow patterns in the booth were experimentally evaluated The average air flow into the exhaust trench in the middle of the booth was measured using a velometer (TSI Velocicalc, TSI, St Paul, Minnesota) Airflow patterns were visualized using smoke tubes, a heated wire smoke generator, and helium-filled soap bubbles generated by a helium bubble generator (Model 33, Sage Action, Ithaca, New York) The helium-filled bubbles are neutrally buoyant and have a diameter of 0 3 to 0 6 cm

Film Thickness

During data collection, the mass of paint used was measured by tracking the weight change of the loaded spray painting gun The film thicknesses were measured by placing metal test strips, 30 x 10 cm pieces of flat steal, on each part The film thickness was measured using a film thickness gauge (Elcometer 245, Elco Instruments, Manchester, United Kingdom)

Computational Fluid Dynamics

A two-dimensional laminar steady state analytical model was created using Fluent UNS 4 2 (Fluent Inc , Lebanon, New Hampshire) to predict the cross-sectional flow field in the downdraft spray paint booth shown in Figure 5 The booth supply air enters through the ceiling at a uniform velocity of 0 15 m/sec (30 feet per minute (fpm)) The air exits the booth along a grate in the floor which was modeled as an outflow boundary measuring 0 78 m (2 feet and 7 inches) in width centered within the booth A uniform structured computational grid was generated using 2,184 quadrilateral elements A second model was built to illustrate the effect of changing the booth geometry on the flow patterns As before, the booth measures 4 2 m (14 feet) in width along the floor and has a height of 2 74 m (9 feet) The right sidewall, however, tapers 0 61 m (2 feet) from the ceiling to the floor On the left side of the booth, the cornice was removed and the inlet air filters were extended to the wall The booth supply air velocity remains at a uniform 0 15 m/sec, and the supply and exhaust are modeled as a velocity inlet and outflow boundary, respectively A structured grid comprising 1,014 quadrilateral cells was generated for this simulation For both booths, Fluent UNS was used to numerically solve the Navier-Stokes equations for the conservation of mass and momentum for laminar flow with no heat transfer [18 19] The laminar model was chosen because smoke visualization studies performed within the actual booth in Figure 5 showed the smooth layers of flow consistent with a laminar flow The first order upwind discretization scheme was used along with the SIMPLE algorithm for the solution of the momentum equations [16 20]

RESULTS

Air Contaminant Concentrations

Anderson impactor results, air contaminant concentrations, average paint film thicknesses, and mass of paint used during each run are listed in Appendix A The ratio of average paint film thickness and mass of paint used during a run was termed "film build " Because the film thickness is proportional to the amount of paint on the parts, this term film build is directly proportional to the efficiency of the spray painting gun A statistical analysis was performed on the logarithms of the total paint mist concentrations measured with the closed-face samplers A one-way analysis of variance using the SAS General Linear Models Procedure was used to evaluate whether the part's orientation affected the paint mist concentration and the film build [21] The orientation significantly affected the log-transformed total paint mist concentration and the film thickness per mass of paint (probability = 0 002 and 0 02, respectively) A multiple comparison test, Tukey's HSD test, was conducted at an overall level of confidence of 95 percent to evaluate the differences among the different treatments Table 1 presents the results of the multiple comparison tests under the columns labeled grouping code When the means have completely different codes, they differ significantly The geometric mean paint mist concentration measured when the bumper was laid across the booth's exhaust trench was significantly higher than when it was parallel to the exhaust trench The film thickness per mass of paint applied varied with orientation However, the mean values of this variable are within 11 percent of each other

Table 1 Paint mist concentrations and film build for each orientation

Orientation		Number	GM[a] Paint Mist Concentration (Closed Face)		Average Film Thickness/Mass of Paint	
Fender	Bumper		(mg/m³)	Grouping[b]	(µm/kg)	Grouping
parallel	Perpendicular	3	14 87	A	0 89	B
parallel	parallel	3	6 04	B	0 99	A
Perpendicular	parallel	3	5 2	B	0 875	B

a GM - geometric mean

b Grouping Code geometric means with different codes differ significantly based upon Tukey's multiple comparison test

Table 2 presents a summary of the air contaminant concentration data for the two different orientations of the bumper Based upon a pooled test, bumper orientation significantly affected the geometric mean total paint and n-butyl acetate concentrations (probability >t=0 007 and 0 0002, respectively) Butyl acetate results were not included in Table 1 because butyl acetate was not detected in two of the three sorbent tubes used when the bumper and fender were parallel to the orientation of the exhaust trench

Table 2 Summary of air contaminant concentrations at different orientations of the bumper

Air Contaminant	n	GM (mg/m³)	GSD	Range
Bumper Perpendicular				
total paint overspray	3	14 9	1 2	12-17
n-butyl acetate	3	114	1.1	102-118
Bumper Parallel				
total paint overspray	6	5 6	1 25	4-8 18
n-butyl acetate	4	30 4	1 14	27-37
HDT	6	3 1	1 66	1 4-6 1

GM - geometric mean
GSD - geometric standard deviation

Ventilation Measurements

The total booth flow was measured to be 3 35 m^3/sec (7100 cfm) The air flow from the ceiling was 0 15 m/sec A two-dimensional view of the airflow patterns in a quiescent booth without the disturbance is presented in Figure 6 Actual airflow traces with helium bubbles and the smoking wire generator indicated that the air flow was much more three-dimensional in shape than can be described by a two-dimensional figure Helium bubbles and smoke indicated that the eddy involves a net flow of air from the lower back corner of the booth toward the front of the booth About 5 or 6 feet from the front of the booth, this air flow made a twisting turn toward the exhaust trench in the floor

The results of the theoretical analysis on the existing booth and a theoretical booth are shown in Figures 7 and 8 The solid path lines are shown in each figure along with the velocity vectors (represented as arrows) The path lines show the flow path of massless particles released from a surface within the computational domain The velocity vectors have been constrained to a fixed length to provide information on the flow patterns only and are not scaled by velocity magnitude The theoretically estimated airflow patterns (see Figure 7) in the existing booth are in substantial agreement with the visually observed airflow patterns (see Figure 6) If the booths could be designed to eliminate these eddies, perhaps exposures could be reduced Figure 8 explores two possible design changes which might minimize eddy formation On the right side of the booth in Figure 8, the cornice is replaced with a slanted wall The eddy is restricted to the lower right side of the booth On the left side of this booth, the cornice has been eliminated and the air inlet filters extend all the way to the wall This eliminates the eddy In both cases, the eddy is not transporting air contaminants into the worker's breathing zone

DISCUSSION

The orientation of the bumper had a significant effect upon the worker's paint overspray concentration When the bumper was laid across the exhaust trench, the paint overspray exposure increased from 6 to 15 mg/m^3 The airflow patterns in this booth and the air motion induced by the spray painting gun jet can explain this result When the worker is painting the bumpers, the spray painting gun's jet is directed toward the eddy at the side of the booth As discussed elsewhere, the spray painting gun's jet is measurable 2 5 meters from the point where paint was being applied to a car [11] This suggests that the spray painting gun's jet has enough momentum to push paint overspray into the eddy on the side of the booth While painting the ends of the bumper, the painter is standing near this eddy The eddy on the side of the booth has the capacity to transport paint overspray to the top of the booth where this recirculated paint overspray is dispersed into the incoming fresh air When the worker was painting the fender, he was always in the center of the booth where the incoming fresh air is less likely to be contaminated by paint overspray in the eddy

The large eddies pictured in Figure 6 are located under the cornices in the booth The cornices are used to hide electrical connections and light fixtures The cornice may be necessary for fire

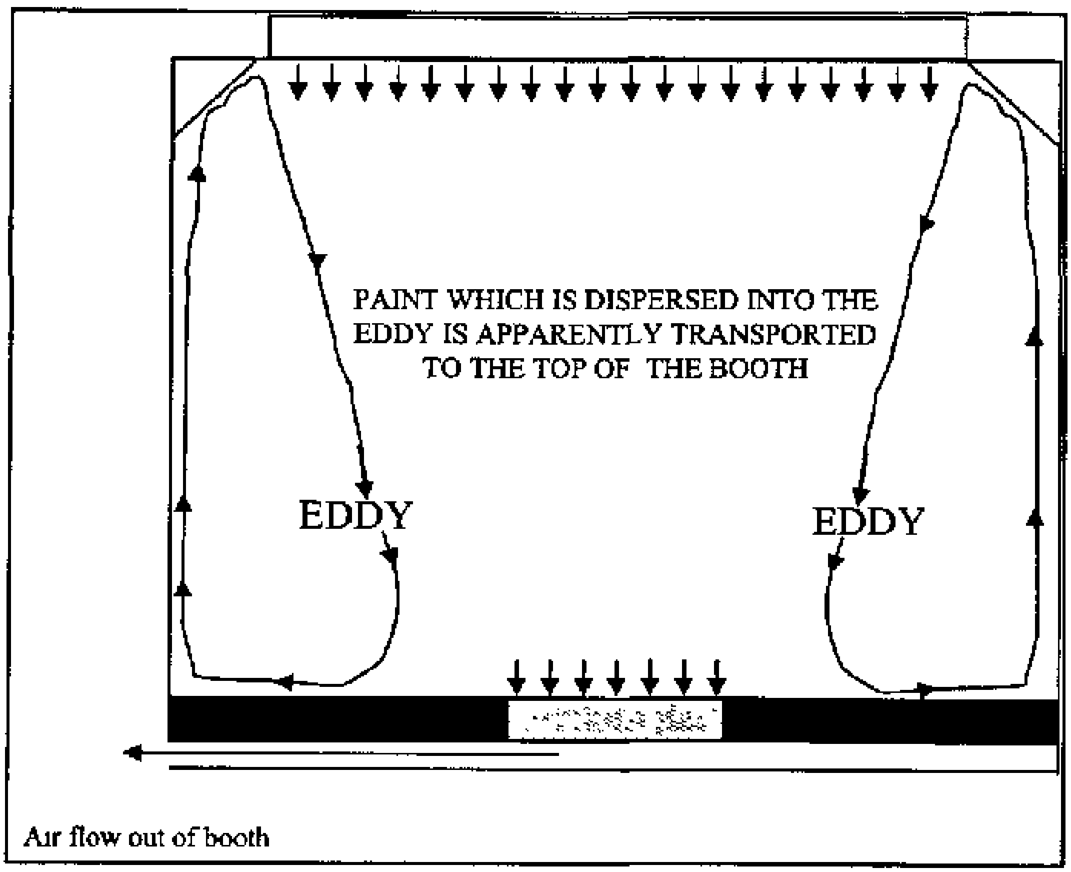

Figure 6 Observed airflow patterns in booth Note, the actual airflow patterns appeared to be more three dimensional

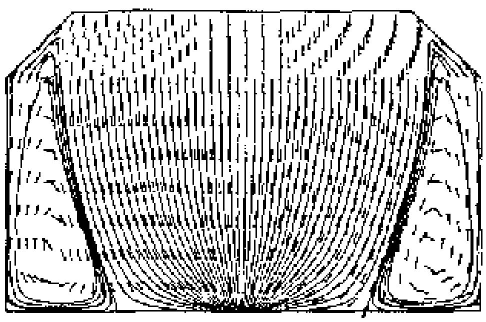

Figure 7 Predicted airflow patterns in existing downdraft booth The arrows indicate direction of air flow The solid lines indicate particle paths The particles were released at the level of the bottom of the cornices

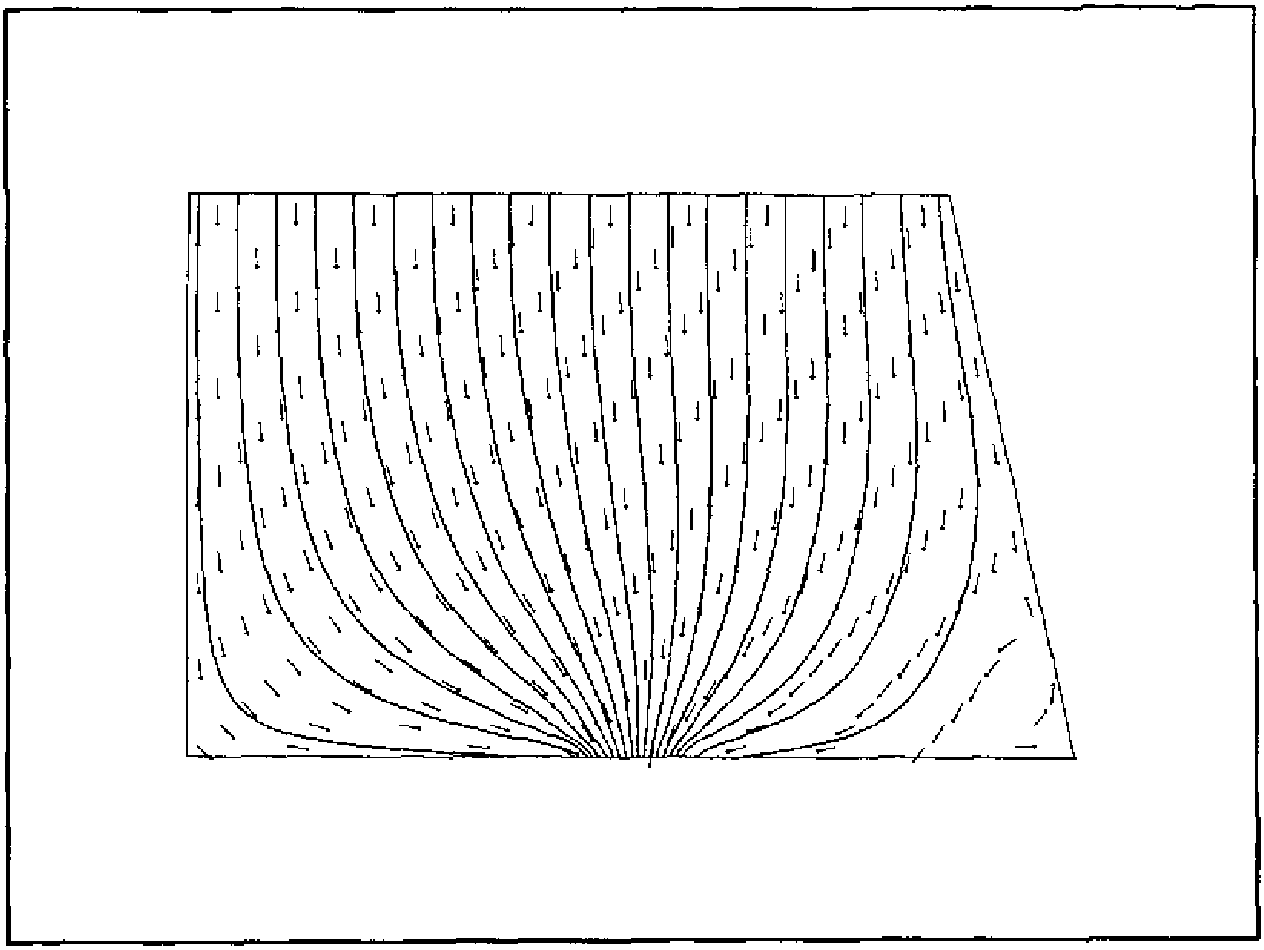

Figure 8 Predicted airflow patterns in a hypothetical booth On the right side of the booth, the cornice was replaced with a slanted wall On the left side of the booth, the cornice was eliminated and the air filter in the ceiling was extended to the wall The solid lines indicate the path of particles released at the ceiling and the arrows indicate the direction of the air flow

safety and to isolate electrical connections from the paint overspray mist However, the cornice causes an eddy which can ultimately lead to the contamination of the incoming air flow A two-dimensional model of air flow in this booth was developed to evaluate the role of the cornice in the development of the eddy The results of the CFD modeling is presented in Figures 7 and 8 Figure 7 shows a two-dimensional model of the current booth The shape of the eddy agrees with observations presented in Figure 6 The model in Figure 8 suggests changes in geometry which minimizes the eddy size

On the right side of the booth, the cornice was extended from ceiling to the floor of the booth Essentially, the right wall of the booth is sloped slightly On the left side of the booth, the cornice was eliminated and the inlet air distribution filter was extended to the wall on the left side of the booth On the left side, the model predicts that the eddy would be eliminated, and on the right side under the slanted wall, the size of the eddy is reduced and the eddy only reaches a height of about 2 feet Thus, these computations suggest that the eddy can be minimized by altering the geometry of the booth

CONCLUSIONS

Part orientation affects worker exposure to paint overspray When parts are painted in a downdraft spray painting booth, the parts need to be oriented so the paint overspray is not directed at eddies which circulate paint overspray into the incoming fresh air Downdraft paint booths should be designed or selected to eliminate eddies which circulate air from the bottom of the booths to heights corresponding to the worker's breathing zone or higher Further analysis of the effect of the spray gun momentum on downdraft booth airflow patterns may provide more realistic information on the effect of booth parameters upon worker exposure to paint overspray

REFERENCES

1 Tornling G, Alexandersson R, Hedenstierna G, Plato N [1990] Decreased Lung Function and Exposure to Diisocyanates (HDI and HDI-BT) in Car Repair Painters Observation On Re-Examination 6 Years After Initial Study Am J Ind Med 17 299-310

2 Oregon Occupational Safety and Health Division [1991] Interim Oregon Occupational Safety and Health Code OAR 437, Division 2 Salem, OR Oregon Occupational Safety and Health Division, Department of Insurance and Finance, Publication AO-1991

3 Myer HE, O'Block ST, Dharmarajan V [1993] A Survey of Airborne HDI, HDI-Based Polyisocyanate and Solvent Concentrations in the Manufacture and Application of Polyurethane Coatings Am Ind Hyg Assoc J 54(11) 663-670

4 Janko M, McCarthy K, Fajer M, Raalte J [1992] Occupational Exposure to 1,6 Hexamethylene Diisocyanate-Based Polyisocyanates in the State of Oregon, 1980-1990 Am Ind Hyg Assoc J 53(5) 331 338

5. Heitbrink WA, Cooper TC, Edmonds MA, Bryant CJ [1993] In-Depth Survey Report Control Technology for Autobody Repair and Painting Shops at Blue Ash Autobody Shop, Blue Ash, Ohio Cincinnati, OH U S DHHS, PHS, CDC, NIOSH, NTIS Pub No PB-93-215838

6 Heitbrink WA, Cooper TC, Edmonds MA, Bryant CJ, Ruch W [1993] In-Depth Survey Report Control Technology for Autobody Repair and Painting Shops at Valley Paint and Body Shop, Amelia, Ohio, May 6, 11-15, June 8, and October 15, 1992 Cincinnati, OH U S DHHS, PHS, CDC, NIOSH, NTIS Pub No PB-93-216190

7 Cooper TC, Heitbrink WA, Edmonds MA, Bryant J, Ruch WE [1993] In-Depth Survey Report Control Technology for Autobody Repair and Painting Shops at Jeff Wyler Autobody Shop, Batavia, Ohio, June 16-19, and July 21, 1992 Cincinnati, OH U S DHHS, PHS, CDC, NIOSH, NTIS Pub No PB-93-216182

8 Heitbrink WA, Cooper TC, Edmonds MA [1993] In-Depth Survey Report Control Technology for Autobody Repair and Painting Shops at Cincinnati Collision Autobody Shop, Blue Ash, Ohio, July 27-30, 1992 Cincinnati, OH U S DHHS, PHS, CDC, NIOSH, NTIS Pub PB-94-118361

9 Heitbrink WA [1993] In-Depth Survey Report Control Technology for Autobody Repair and Painting Shops at Team Chevrolet, Colorado, Springs, Colorado, December 8-11, 1992 Cincinnati, OH U S DHHS, PHS, CDC, NIOSH, NTIS Pub No PB-94-151677

10 Heitbrink WA, Fischbach TJ, Edmonds MA [1994] In-Depth Survey Report Evaluation of Spray Gun Technology for Occupational Exposure to Auto Paint Shop Hazards at DeVilbiss Automotive Refinishing Products, Maumee, Ohio, September 14-19, 1992, and July 6-8, 1993 Cincinnati, OH U S DHHS, PHS, CDC, NIOSH, NTIS Pub No PB-94-194669

11 Heitbrink W, Wallace M, Bryant C, Ruch W [1995] Control of Paint Overspray in the Autobody Repair Shops Am Ind Hyg Assoc J 56(10)1023-1032

12 Heitbrink WA, Verb RH, Fischbach TJ, Wallace ME [1996] A Comparison of Conventional and High Volume-Low Pressure Spray Painting Guns Am Ind Hyg Assoc J 57(3) 304-310

13 NIOSH [1998] NIOSH Method 0500 In Eller PM, Cassinelli ME, eds NIOSH manual of analytical methods 4th ed Cincinnati, OH U S Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 98-118

14 NIOSH [1998] NIOSH Method 1450 In Eller PM, Cassinelli ME, eds NIOSH manual of analytical methods 4^{th} ed Cincinnati, OH U S Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 98-118

15 NIOSH [1998] NIOSH Method 1501 In Eller PM, Cassinelli ME, eds NIOSH manual of analytical methods 4^{th} ed Cincinnati, OH U S Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 98-118

16 Bayer Corporate Industrial Hygiene Laboratory [1996] Determination of Isocyanates in Spray Mist Environments with an Impinger Containing N-(4-nitrobenzly)-proplyamine in Toluene and Analysis by High Performance Liquid Chromatography Bayer Product Safety and Regulatory Affairs, 100 Bayer Road, Pittsburgh, Pennsylvania

17 Marple VA, Rubow KL, Olson BA [1993] Inertial, Gravitational, Centrifugal, and Thermal Collection Techniques In Willeke K, Baron PA, eds Aerosol Measurement Principle, Technique, and Application New York, NY Van Nostrand

18 Bird RB, Stewart WE, Lightfoot EN [1960] Transport Phenomena New York, NY John Wiley

19 Pantankar SV [1980] Numerical Heat Transfer and Fluid Flow New York, NY Hemisphere Publishing Corporation

20 Fluent Incorporated [1997] FLUENT/UNS & RAMPANT User's Guide Vol. 2 (1st ed) Lebanon, NY Fluent Incorporated

21 SAS Institute [1990] SAS/STAT User's Guide Ver 6, 4^{th} Ed , Vol 2 Cary, NC SAS Institute

APPENDIX – RAW DATA

Anderson Impactor B-Sampling the Base or Color Coat BASF, Whitehouse, OH 09 25 1997						
Filter #	Stage #	Size Range (µm)	Root Mean Diameter (µm)	root mean diameter adjusted for low flow	Mass fraction Fraction	Mass (mg)
Bottom	Bottom	0-0 4	0 4 & smaller	0 72 & smaller	0 00057	0 04
F	7	0 4-0 7	0 53	0 72	0 00142	0 1
7	6	0 7-1 1	0 88	1 20	0 00909	0 64
6	5	1 1-2 1	1 52	2 07	0 0287	2 02
5	4	2 1-3 3	2 63	3 58	0 02487	1 75
4	3	3 3-4 7	3 94	5 37	0 07261	5 11
3	2	4 7–5 8	5 22	7 11	0 07531	5 3
2	1	5 8-9 0	7 22	9 84	0 10415	7 33
1	0	9 0 and greater	9 0 & larger	12 3 & larger	0 68329	48 09
		painting time 123minutes			total weight	70 38 (mg)
		Pump Flow 15 12 liters/min			mass concentration	37 8 mg/m³

Anderson Impactor A-Sampling the Clear Coat BASF, Whitehouse, OH 09 25 1997						
Filter #	Stage #	Size Range (µm)	Root Mean Diameter (µm)	root mean diameter adjusted for low flow rate	Mass Fraction	Mass (mg/filter)
Bottom	Bottom	0-0 4	0 4 & smaller	0 72 & smaller	0 005	0 46
F	7	0 4-0 7	0 53	0 72	0 0020	0 22
7	6	0 7-1 1	0 88	1 20	0 011	0 95
6	5	1 1-2 1	1 52	2 08	0 029	2 59
5	4	2 1-3 3	2 63	3 59	0 044	3 91
4	3	3 3-4 7	3 94	5 38	0 060	5 38
3	2	4 7--5 8	5 22	7 13	0 036	3 19
2	1	5 8-9 0	7 22	9 86	0 085	7 59
1	0	9 0 and greater	9 0 & larger	12 3 & larger	0 730	64 98
		painting time 117 minutes		total weight 89 27 (mg)		
		flow rate15 12 liters/min		concentration 50 46		

Total Particulate, Closed and Open Filter Cassettes, BASF, Whitehouse, OH 09/25/1997 and 01/14-16/1998											
Date	Run	Parts Orientation	Filter face Number	Base Coat Time, min	Clear Coat Time, min	Base Coat Time, min	Clear Coat Time, min	Total Time, min	Pump Flow Rate,cc/min	Total Particulate mg/sample	mg/m^3
9/25/97	1	FpBa	clsd	15 70	12 92	14 57	12 37	55 55	5041	3 7	13 21
9/25/97	1	FpBa	clsd	15 70	12 92	14 57	12 37	55 55	4980	3 1	11 21
9/25/97	2	FpBa	clsd	14 73	13 67	14 53	13 50	56 43	5004	4 83	17 10
9/25/97	2	FpBa	open	14 73	13 67	14 53	13 50	56 43	4967	4 61	16 45
9/25/97	3	FpBa	clsd	13 63	14 03	13 05	13 25	53 97	4980	4 3	16 00
9/25/97	3	FpBa	open	13 63	14 03	13 05	13 25	53 97	5041	5 04	18 53
1/14/98	1	FaBp	clsd	12	12	12 67	12 57	49 24	4728	0 96	4 12
1/14/98	1	FaBp	open	12	12	12 67	12 57	49 23	4922	2 21	9 12
1/15/98	2	FaBp	clsd	11 42	11 58	12 15	12 85	48	4728	1 41	6 21
1/15/98	2	FaBp	open	11 42	11 58	12 15	12 85	48	4922	1 77	7 49
1/15/98	3	FaBp	clsd	11 07	11 92	12 12	13 37	48 47	4728	1 28	5 59
1/15/98	3	FaBp	open	11 07	11 92	12 12	13 37	48 47	4922	0 69	2 89
1/15/98	4	FpBp	clsd	12 40	12 23	11 38	13 55	49 57	4728	1 15	4 91
1/15/98	4	FpBp	open	12 40	12 23	11 38	13 55	49 57	4922	1 26	5 16
1/16/98	5	FpBp	clsd	11 48	12 97	12 90	13 90	51 25	4728	1 38	5 70
1/16/98	5	FpBp	open	11 48	12 97	12 90	13 90	51 25	4922	0 79	3 13
1/16/98	6	FpBp	clsd	12 08	13 60	13 73	12 57	51 98	4728	2 01	8 18
1/16/98	6	FpBp	open	12 08	13 60	13 73	12 57	51 98	4922	1 8	7 04

Sorbent Tubes, BASF, Whitehouse, OH 09/25/1997 and 01/14-16/1998, Part I

Date	Run	Tube Number	Parts Orientation	Base Coat Time,min	Clear Coat Time,min	Base Coat Time,min	Clear Coat Time,min	Total Time,min	Flow Rate, cc/min
9/25/97	1	B-1-1	FpBa	15 70		14 57		30 27	200
9/25/97	1	C-1-1	FpBa		12 92		12 37	25 29	199
9/25/97	2	B-2-1	FpBa	14 73		14 53		29 26	200
9/25/97	2	C-2-1	FpBa		13 67		13 50	27 17	199
9/25/97	3	B-3-1	FpBa	13 63		13 05		26 68	200
9/25/97	3	C-3-1	FpBa		14 03		13 25	27 28	199
9/25/97	blank	B-4-1							
9/25/97	blank	B-5-1							
9/25/97	blank	B-6-1							
9/25/97	blank	B-7-1							
9/25/97	blank	C-4-1							
9/25/97	blank	C-5-1							
9/25/97	blank	C-6-1							
9/25/97	blank	C-7-1							
1/14/98	1	DEV-100	FaBp	12 00	12 00	12 67	12 57	49 23	197
1/15/98	2	DEV-93	FaBp	11 42	11 58	12 15	12 85	48 00	197
1/15/98	3	DEV-95	FaBp	11 07	11 92	12 12	13 37	48 47	197
1/15/98	4	DEV-99	FpBp	12 40	12 23	11 38	13 55	49 57	197
1/16/98	5	DEV-96	FpBp	11 48	12 97	12 90	13 90	51 25	197
1/16/98	6	DEV-98	FpBp	12 08	13 60	13 73	12 57	51 98	197
1/15/98	blank 1	DEV-94							
1/15/98	blank 2	DEV-92							
1/16/98	blank 3	DEV-97							
1/16/98	blank 4	DEV-91							

Sorbent Tubes, BASF, Whitehouse, OH 09/25/1997 and 01/14-16/1998, Part I								
Tube Number	N-Butyl Acetate		Total Xylenes		Toluene		PGMEA	
	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3
B-1-1	0 56	92 50	0 108	17 84	0 0059	0 97	0 049	8 09
C-1-1	0 13	25 83	0 106	21 06	0 029	5 76	0 019	3 78
		118 33		38 90		6 74		11 87
B-2-1	0 56	95 69	0 296	50 58	0 0057	0 97	0 047	8 03
C-2-1	0 15	27 74	0 124	22 93	0 033	6 10	0 021	3 88
		123 44		73 51		7 08		11 92
B-3-1	0 42	78 71	0 091	17 05	0 0043	0 81	0 034	6 37
C-3-1	0 13	23 95	0 118	21 74	0 033	6 08	0 02	3 68
		102 66		38 79		6 88		10 06
B-4-1	ND		0 054		0 032		ND	
B-5-1	ND		ND		ND		ND	
B-6-1	ND		ND		ND		ND	
B-7-1	ND		0 346		0 12		ND	
C-4-1	ND		0 083		0 01		ND	
C-5-1	ND		ND		ND		ND	
C-6-1	ND		ND		ND		ND	
C-7-1	ND		0 397		0 15		ND	
LOD	0 002		0 001		0 001		0 004	
LOQ	0 007		0 003		0 003		0 01	
	average	114 81	average	50 40	average	6 90	average	11 28
DEV-100	0 36	37 12	0 11	11 34	0 05	5 16	0 07	7 22
DEV-93	0 29	30 67	0 093	9 84	0 017	1 80	0 04	4 23
DEV-95	0 26	27 23	0 083	8 69	0 019	1 99	0 052	5 45
	average	31 67	average	9 96	average	2 98	average	5 63
DEV-99	0 002	0 20	ND	ND	0 001	0 10	ND	ND
DEV-96	0 28	27 73	0 098	9 71	0 056	5 55	0 057	5 65
DEV-98	0 002	0 20	ND	ND	ND	ND	ND	ND
	average	27 73	average	9 71	average	5 55	average	5 65
DEV-94	ND		ND		0 001		ND	
DEV-92	ND		ND		0 001		ND	
DEV-97	ND		ND		ND		ND	
DEV-91	ND		ND		ND		ND	
LOD	0 0009		0 002		0 0009		0 002	
LOQ	0 003		0 007		0 003		0 007	

LOD, LOQ - limits of detection and quantitation, respectively

Impinger (Polyisocyanates), BASF, Whitehouse, OH 01/14-16/1998

Date	Run	Parts Orientation	Impinger Number	Clear Coat Time,min	Clear Coat Time,min	Total Time,min	Flow Rate, cc/min	Desmodur –3391 µg	µg/m^3	Tolonate HDT µg	µg/m^3
1/14/98	1	FaBp	#1	12	12 57	24 57	1721	300	7096	260	6150
1/15/98	2	FaBp	#2	11 58	12 85	24 43	1721	220	5232	180	4281
1/15/98	3	FaBp	#3	11 92	13 37	25 28	1721	75	1724	60	1379
1/15/98	4	FpBp	#4	12 23	13 55	25 78	1721	140	3155	110	2479
1/16/98	5	FpBp	#5	12 97	13 90	26 87	1721	200	4325	160	3460
1/16/98	6	FpBp	#6	13 60	12 57	26 17	1721	150	3331	130	2887

Material Used (Base and Clear Coats) and Film Thickness, BASF, Whitehouse, OH 09/25/1997 and 01/14-16/1998, Part I

Date	Run	Parts Orientation	Base Coat 1 (gm)	Base Coat 2 (gm)	Total Base Coat, (gm)	Clear Coat 1 (gm)	Clear Coat 2 (gm)	total Clear Coat (gm)	Base +Clear (gm)	Total Painting time (min)	average paint usage rate (gm / min)
9/25/97	1	FpBa	1720	1565	3285	1326	1572	2898	6183	55 55	111 3
9/25/97	2	FpBa	1737	1624	3361	1542	1472	3014	6375	56 43	113 0
9/25/97	3	FpBa	1578	1535	3113	1552	1470	3022	6135	53 97	113 7
1/14/98	1	FaBp	1405	1517	2922	1245	1319	2564	5486	49 23	111 4
1/15/98	2	FaBp	1359	1384	2743	1354	1397	2751	5494	48	114 5
1/15/98	3	FaBp	1268	1268	2536	1235	1335	2570	5106	48 47	105 3
1/15/98	4	FpBp	1403	1166	2569	1199	1114	2313	4882	49 57	98 5
1/16/98	5	FpBp	1366	1531	2897	1379	1413	2792	5689	51 25	111 0
1/16/98	6	FpBp	1388	1491	2879	1364	1440	2804	5683	51 98	109 3

Material Used (Base and Clear Coats) and Film Thickness, BASF, Whitehouse, OH 09/25/1997 and 01/14-16/1998, Part II

		Parts	BaseCoat	BaseCoat	average BaseCoat	ClearCoat	ClearCoat	average Clear Coat	Average film thickness
Date	Run	Orientation	(1/1000s in)	(1/1000s in)	(1/1000s in)	(1/1000s in)	(1/1000s in)	(1/1000s in)	(1/1000s in)
9/25/97	1	FpBa	1 0	1 8	1 4	3 7	4 1	3 9	5 3
9/25/97	2	FpBa	1 5	0 7	1 1	4 0	4 4	4 2	5 3
9/25/97	3	FpBa	1 6	1 8	1 7	4 2	3 9	4 1	5 8
1/14/98	1	FaBp	0 6	1 2	0 9	4 0	4 1	4 1	5 0
1/15/98	2	FaBp	1 3	1 1	1 2	3 4	3 8	3 6	4 8
1/15/98	3	FaBp	1 0	1 1	1 1	3 5	3 7	3 6	4 7
1/15/98	4	FpBp	1 4	1 2	1 3	3 7	3 6	3 7	5 0
1/16/98	5	FpBp	1 1	1 4	1 3	4 6	4 2	4 4	5 7
1/16/98	6	FpBp	1 1	1 0	1 1	4 5	4 4	4 5	5 5