CONTROL TECHNOLOGY FOR AUTOBODY REPAIR AND PAINTING SHOPS

at

Kay Parks/Dan Meyer Autorebuild
Tacoma, Washington

REPORT WRITTEN BY:
William A. Heitbrink
Marjorie A. Edmonds
Thomas J. Fischbach

REPORT DATE:
September 1992

REPORT NO.:
ECTB 179-12a

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
4676 Columbia Parkway
Cincinnati, Ohio 45226

DISCLAIMER

PLANT SURVEYED:	Kay Parks/Dan Meyer Autorebuild 3102 South Twelfth Street Tacoma, Washington 98405
SIC CODE:	7531
SURVEY DATE:	September 16-19, 1991
SURVEY CONDUCTED BY:	William A. Heitbrink Marjorie A. Edmonds
EMPLOYER REPRESENTATIVES CONTACTED:	Dan and Sue Meyer, Owners
EMPLOYEE REPRESENTATIVE:	Ron Kinzel International Machinists and Aerospace
WORKERS UNION LOCAL LODGE 1152:	Tacoma Mall Boulevard Tacoma, Washington 98409

TABLE OF CONTENTS

INTRODUCTION 1
Shop Description 2
Description of Ventilated Sanders 3
Spray Painting Booth and Room 3

POTENTIAL HAZARDS 5
Diisocyanates and Their Oligomers 5
Organic Solvents 6
Metals 7

EXPOSURE EVALUATION CRITERIA 8

EVALUATION PROCEDURES 10
Air Contaminant Exposure Monitoring 10
Video Exposure Monitoring 11
Ventilation Measurements 12

RESULTS 13
Ventilation Measurements 13
Air Sampling Results 14
Video Exposure Monitoring 16

DISCUSSION 20
Airflow Recommendations for the Spray Painting Booths 20

CONCLUSIONS 21

REFERENCES 22

APPENDIX A
Particulate Concentrations During Sanding and Spray Painting . . . 26

APPENDIX B
Concentration of Organic Vapors in Parts Per Million During Spray Painting 29

APPENDIX C
Computation of Limits of Detection and Quantitation 31

APPENDIX D
Statistical Analysis of the Real-time Data 34

SUMMARY

Orbital and in-line sanders (Hutchins, Pasadena CA) with built-in high-velocity, low-volume exhaust hoods were studied in an autobody repair shop. Measurements made with an aerosol photometer showed that the use of the in-line sander reduced worker exposure to aerosols by approximately a factor of 8. When air samples were collected in the worker's breathing zone, to measure worker exposure to total particulate, a quantifiable mass of aerosol (limit of quantitation = 0.1 mg total particulate) was not collected on the filter. Based upon a statistical treatment of the filters' weight changes and the sample volume, the total particulate exposures during sanding were estimated to be 1.5 mg/m^3 when using a 6-inch diameter orbital sander and 0.3 mg/m^3 when using an in-line sander. In addition, the air samples were also analyzed for lead (limit of detection (LOD) = 2 μg/filter), cadmium (LOD = 1 μg/filter), and chromium (LOD = 1 μg/filter). These metals were not detected on any of the filters.

In addition, air samples for particulate and solvent exposures were collected in the worker's breathing zone while he spray painted cars and car parts outside of a spray painting booth. During such spray painting operations, less than one pint of paint is used. Solvent and total particulate exposures were below exposure limits promulgated by OSHA and recommended by NIOSH.

Keywords: SIC 75319, total particulate, autobody repair, spray painting, toluene, xylene, acetone, ventilated sanders.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is the primary federal organization engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of 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 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 of health hazards prevention and control.

Since 1976, ECTB has conducted several assessments of health hazard control technology based on industry, common industrial process, or specific control techniques. The objective of each of these studies has been to document and evaluate effective techniques for the control of potential health hazards in the industry or process of interest, and to create a more general awareness of the need for, or availability of, effective hazard control measures.

A study of autobody repair is being undertaken by the Engineering Control Technology Branch to provide control technology information for preventing occupational disease in this industry. This project is part of a NIOSH special initiative on small business and will be accomplished by developing and evaluating control strategies and disseminating control technology information to a small business. Several types of candidate small businesses with potential hazards were originally identified from letters from OSHA 7(c)(1) state consultation programs. From these letters, contacts with state consultation program representatives, discussions between DSHEFS and DRDS, and review of the literature, small businesses with potential hazards were ranked as to the best candidate for a control technology study. From the list of candidate small businesses, autobody repair and painting shops were one of several potential industries that were selected for study.

The objective of the overall study on autobody repair and painting shops is to provide these shops information about practical, commercially available, control methods that reduce worker exposure to air contaminants (e.g., isocyanates, refined petroleum solvents, spray paint mists, and airborne particles). To develop this information, commercially available control methods need to be evaluated in actual shops. Control measures to be studied include: ventilated sanders and welders, vehicle preparation stations, and spray painting booths. The results of individual plant/facility evaluations and information available from the literature will be used to develop recommendations on controlling worker exposure to air contaminants in autobody repair and painting shops. Then, this control technology information will be disseminated to autobody workers, owners, and operators of autobody repair and painting shops, and safety and health professionals.

The purpose of this specific site visit was to evaluate orbital and in-line sanders with high-velocity, low-volume (HVLV) exhaust hoods. These sanders exhaust a small volume of air through the sanding pad to capture the sanding dust at its source. This control has application to all types of sanding operations. Also, air contaminant exposures were measured while spray painting was done outside of a spray painting booth. In addition, monitoring was conducted to evaluate whether this practice caused excessive worker exposure to air contaminants.

Shop Description

This autobody shop employs 14 workers; 10 workers repair cars and 4 workers paint cars. It has been in operation for 20 years and repairs an average of 5.5 cars per day. The layout of the shop is schematically illustrated in Figure 1. In the autobody repair area, the cars' structural damage is repaired. This involves the repair and replacement of damaged parts. During these activities, the workers may be exposed to aerosols from sanding, grinding, and welding. After the cars are repaired, they are prepared for painting in the vehicle preparation area. This involves some sanding to

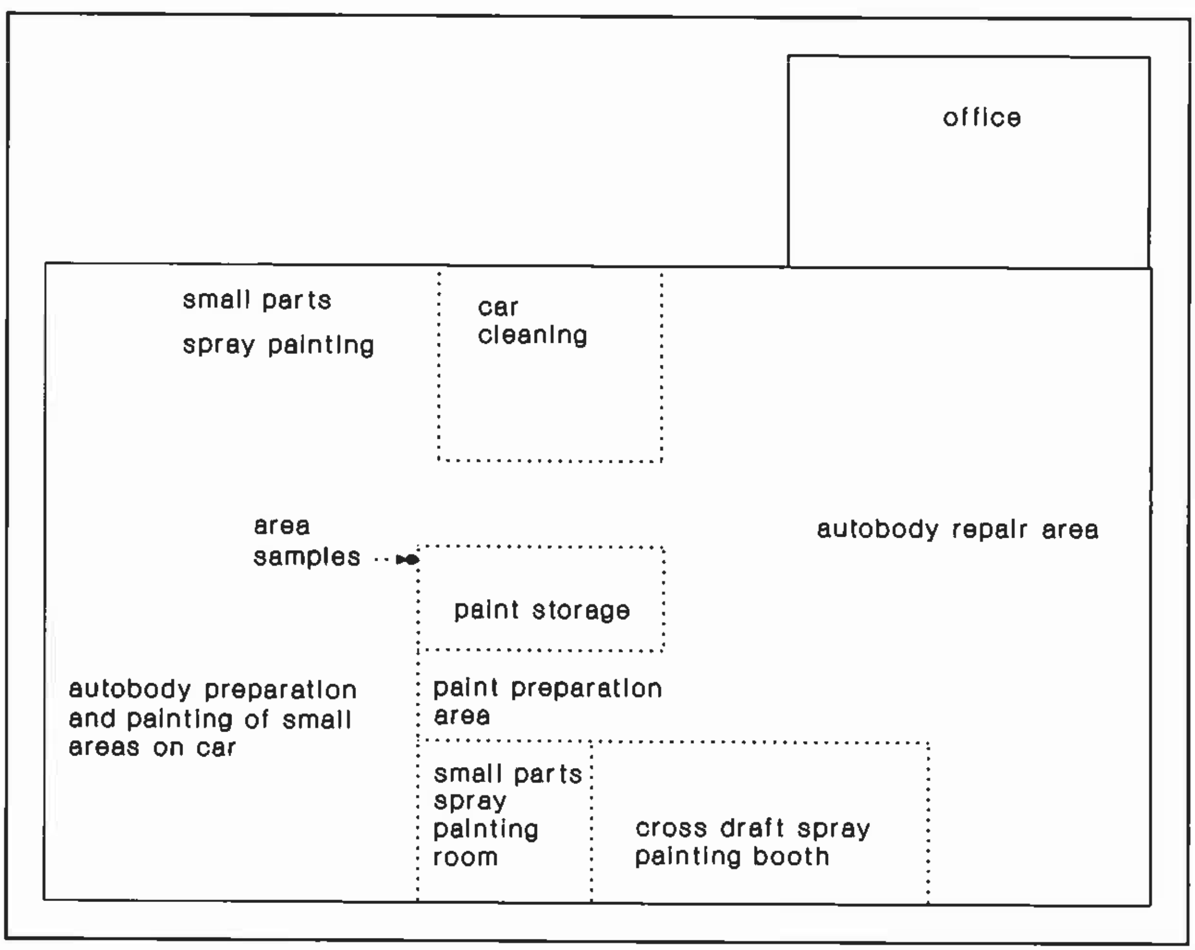

Figure 1. Schematic illustration of autobody shop's layout.

remove old paint and to provide a smooth surface for the paint. According to shop rules, spray painting outside of a spray painting booth in the vehicle preparation area is permitted when these two conditions are both satisfied:

1. Less than a pint of paint is used; and,
2. The paint does not contain isocyanates.

If more than a pint of paint is needed, or if the paint contains isocyanates, the painting is done in a spray painting booth.

Ventilated sanders and spray painting booths are used to control worker exposure to air contaminants. Ventilated sanders are used to control air contaminants generated during sanding. A ventilated spray painting booth and a small parts spray painting booth are used for spray painting jobs involving either isocyanates or more than one pint of paint. The booths are used for spray painting cars and the small parts spray painting booth is used for spray painting autobody parts. Air-supplied respirators are worn by workers in the spray painting booth and the small parts spray painting booth. When spray painting is conducted outside of a spray painting booth, workers wear half-face piece air purifying respirators.

Description of Ventilated Sanders

Three types of sanders (Hutchins Manufacturing Company, Pasadena, CA) are used in this autobody shop: 6-inch and 8-inch diameter orbital sanders and a straight-line sander. These sanders were designed for use with a central vacuum system. Air is exhausted through holes in the sander pads. The sand paper contains prepunched holes which match the holes in the pad. Some details of these Hutchins sanders are described in Table 1.

The exhaust from these sanders is attached to a vacuum hose. At this connection, the static pressure in the vacuum line is 6 inches of Hg. The flexible vacuum hose and compressed air lines are supported by retractors shown in Figure 2. Throughout this shop, 22 work stations have these vacuum hoses. After flowing through the vacuum tubing, the air flows through piping into a bag house where it is filtered. The airflow is provided by a 15 horse power turbine. The total installed cost for this system was $38,000 in 1987.

Spray Painting Booth and Room

Although the spray painting booth and spray painting room were not the focus of this field investigation, some data was taken in the two spray painting booths at this autobody shop. Cars entering or leaving the cross draft spray painting booth had to pass through the small parts spray painting room. The small parts spray painting room was 14 feet wide, 12.6 feet high, and 19 feet long. When the doors to this room were closed, this room lacked makeup air. Air is exhausted from this room through a plenum which is located next to the wall separating the spray painting room from the cross draft spray painting booth. According to the owner, the spray painting booth was 12 feet high and 14 feet wide. The internal configuration of this spray painting booth was not documented.

Table 1
Description of Sander Study

Type of Sander	Hutchins Model Number	Action	Description of Pad
6-inch	4500va	random orbit	A 6-inch diameter pad. The sand paper has 6, 0.4 inch-diameter holes on a circle 1.5 inches from the edge of the sand paper.
8-inch	4001ba	random orbit	A 8-inch diameter pad. The sand paper has 12, 0.45-inch diameter holes on a circle 0.375 inches from the edge of the sand paper.
in-line sander	2000 (Hustler)	straight - line	The abrasive pad is 2.75 inches wide and 17.5 inches long. Along the length of the sand paper, two rows of nine equally spaced holes are located 0.5 inches from the edge of the sandpaper. The holes are 0.45 inches in diameter.

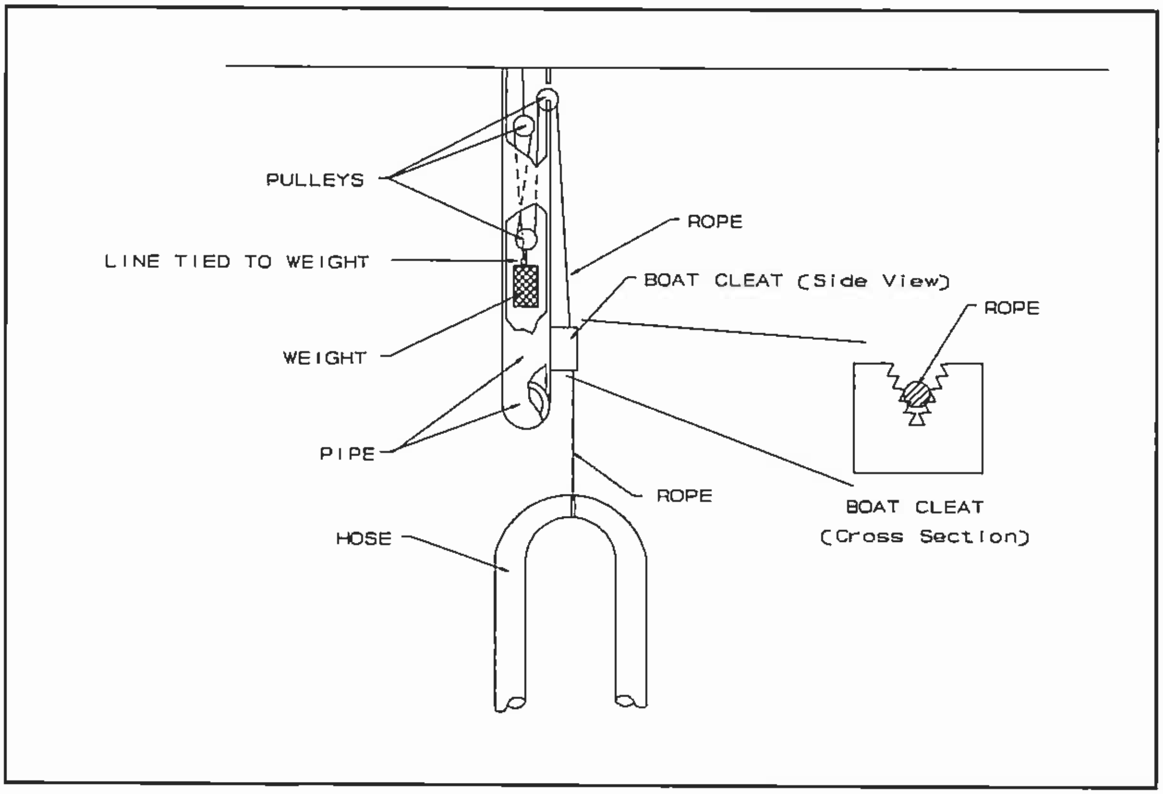

Figure 2. Retractor for vacuum hose and pressure line used to operate the sanders.

POTENTIAL HAZARDS

Workers involved in autobody repair can potentially be exposed to a multitude of air contaminants. During structural repair, activities such as sanding, grinding, and welding generate aerosols which are released into the worker's breathing zone. If the surface of the car being repaired contains toxic metals such as lead, cadmium, or chromium, exposure to these metals is possible. Workers who paint cars can be exposed to organic solvents, hardeners, which may contain isocyanate resins, and pigments, which may contain toxic components.

The International Agency for Research on Cancer (IARC) has reviewed the health effects associated with being a painter.[1] In the IARC publication, the term "painters" included workers who apply paint to surfaces during construction, furniture manufacturing, automobile manufacturing, metal products manufacturing, and 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 nonallergic contact dermatitis, chronic bronchitis, asthma, and adverse effects on the central nervous system. Some of the health effects for specific air contaminants are briefly summarized in the following paragraphs.

Diisocyanates and Their Oligomers

The unique feature of all diisocyanate-based compounds is that they contain two -N=C=O functional groups, which readily react with compounds containing active hydrogen atoms to form urethanes. The chemical reactivity of diisocyanates, and their ability to cross-link, makes them ideal for use in surface coatings, polyurethane foams, adhesives, resins, and sealants. Diisocyanates are usually referred to by their specific acronym; e.g., TDI for toluene diisocyanate or HDI for hexamethylene diisocyanate.[2] To reduce the inhalation exposure to monomers due to vaporization, the isocyanate monomers are prepolymerized into oligomers. These prepolymers are believed to be trimers of the monomer. In commercial spray painting operations, the monomer is usually less than 2 percent paint by weight. However, the oligomers still pose an inhalation hazard to the workers as an aerosol.

Experience has shown that diisocyanates cause irritation to the skin, mucous membranes, eyes, and respiratory tract. Worker exposure to high concentrations may result in chemical bronchitis, chest tightness, nocturnal dyspnea (shortness of breath), pulmonary edema (fluid in the lungs), and reduced lung function.[3,4] The most important and most debilitating health effect from exposure to diisocyanates is respiratory and dermal sensitization. After sensitization, any exposure, even to levels below any occupational exposure limit or standard, will produce an allergic response that may be life threatening.[5,6] The only effective treatment for the sensitized worker is cessation of all diisocyanate exposure.[7]

Organic Solvents

Occupational exposure to organic solvents can cause neurotoxic effects that can include dizziness, headache, an alcohol-like intoxication, narcosis, and death from respiratory failure.[8] Automotive spray painters exposed to organic solvents are reported to have decreases in motor and nerve conduction velocities.[9] In addition, organic solvents such as acetone, toluene, and xylene can cause eye, nose, and throat irritation.[10] Dermal exposure to organic solvents can defat the skin and, thereby, increase the uptake of these solvents by the body. In addition, dermal exposure can cause dermatitis. Some health effects attributed to specific organic solvents are briefly summarized:

Acetone

Few adverse health effects have been attributed to acetone despite widespread use for many years. Awareness of mild eye irritation occurs at airborne concentrations of about 1000 ppm. Very high concentrations (12000 ppm) depress the central nervous system, causing headache, drowsiness, weakness, and nausea. Repeated direct skin contact with the liquid may cause redness and dryness of the skin.[11] Exposures over 1000 ppm cause respiratory irritation, coughing, and headache.[12]

n-Butyl Acetate

At concentrations exceeding 150 ppm, significant irritation of the eyes and respiratory tract are reported in the literature.[12]

n-Butyl Alcohol

n-Butyl alcohol is an irritant to the eyes and the mucous membranes of nose and throat. Exposures over 200 ppm can cause keratitis.[10] Eye irritation and headaches have been reported at concentrations in excess of 50 ppm.[12] Exposure to n-butyl alcohol is reported to increase hearing losses for workers who are also exposed to noise.

Ethyl Acetate

Ethyl acetate vapor is irritating to the eyes and respiratory passages of humans at concentrations above 400 ppm.[12] In animals it has a narcotic effect at concentrations of over 5000 ppm.

Isopropyl Alcohol

At exposures above 400 ppm, irritation to the eyes, nose, and throat are reported. Above 800 ppm, the symptoms intensified.[12]

Trimethyl Benzene

Trimethyl benzene has been reported to cause nervousness, anxiety, and asthmatic bronchitis.[12]

Toluene

Toluene can cause irritation of the eyes and respiratory tract, dermatitis, and central nervous system depression.[10] At concentrations of 200 ppm or less, complaints of headaches, lassitude, and nausea have been reported. At concentrations of 200-500 ppm, loss of memory, anorexia, and motor impairment are reported.[12] In addition, muscle impairment and increased reaction time can occur at exposures of greater than 100 ppm.

Xylene

Xylene vapor may cause irritation of the eyes, nose, and throat. Repeated or prolonged skin contact with xylene may cause drying and defatting of the skin which may lead to dermatitis. Liquid xylene is irritating to the eyes and mucous membranes, and aspiration of a few milliliters may cause chemical pneumonitis, pulmonary edema, and hemorrhaging. Repeated exposure of the eyes to high concentrations of xylene vapor may cause reversible eye damage.[13] At concentrations between 90 and 200 ppm, impairment of body balance, manual coordination, and reaction times can occur. Acute exposure to xylene vapor may cause central nervous system depression and minor reversible effects upon liver and kidneys.[1] Workers exposed to concentrations above 200 ppm complain of loss of appetite, nausea, vomiting, and abdominal pain. Brief exposure of humans to 200 ppm has caused irritation of the eyes, nose, and throat.[14]

Metals

Toxic metals such as lead, chromium, and cadmium may be used as pigments in some paints. As a result, welding and sanding on these surfaces may involve occupational exposure to toxic metals. In addition, autobody welding will involve exposure to welding fumes. Health effects attributed to specific metals are discussed below:

Cadmium

Cadmium is a toxic heavy metal which may enter the body either by ingestion (swallowing) or by inhalation (breathing) of cadmium metal or oxide. Once absorbed into the body, cadmium accumulates in organs throughout the body, but major depositions occur in the liver and kidneys.[15] Acute inhalation exposure to high levels of cadmium can cause respiratory irritation and pulmonary edema. In addition, cadmium exposure causes kidney damage.[16] Chronic exposure may lead to emphysema of the lungs and kidney disease which may be associated with hypertension.[17] After finding that exposure to cadmium has been associated with excess respiratory cancer deaths among cadmium production workers, NIOSH has concluded that cadmium is a potential occupational carcinogen.[18]

Chromium

Some paints may contain chromates hexavalent chromium as a pigment. These compounds can produce health effects such as contact dermatitis, irritation and ulceration of the nasal mucosa, and perforation of the nasal septum.[16] Certain insoluble hexavalent chromium compounds are suspect carcinogens.[19]

Lead

Lead adversely affects several organs and systems. The four major target organs and systems are the central nervous system, the peripheral nervous system, kidney, and hematopoietic (blood-forming) system.[20] Inhalation or ingestion of inorganic lead can cause loss of appetite, metallic taste in the mouth, constipation, nausea, pallor, blue line on the gum, malaise, weakness, insomnia, headache, muscle and joint pains, nervous irritability, fine tremors, encephalopathy, and colic.[16] Lead exposure can result in a weakness in the wrist muscles known as "wrist drop," anemia (due to lower red blood cell life and interference with heme synthesis), proximal kidney tubule damage, and chronic kidney disease.[21,22] Lead exposure is associated with fetal damage in pregnant women.[16] Lastly, elevated blood pressure has been positively related to blood lead levels.[23,24]

EXPOSURE EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week, for a working lifetime without experiencing adverse health effects. Table 2 summarizes exposure limits for air contaminants which may be present in autobody shops. It is, however, important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy).

In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the evaluation criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes and thus, potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria in the United States that are used for the workplace are: 1) NIOSH Recommended Exposure Limits (RELs); 2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs); and 3) the U.S. Department of Labor (OSHA) Permissible Exposure Limits (PELs). The OSHA PELs are required to

Table 2

Occupational Exposure Limits

Substance	NIOSH Recommended Exposure Limit[25]	OSHA Permissible Exposure Limit[28]		ACGIH Threshold Limit Value (TLV)[27]	
	TWA[a]	TWA[b]	STEL[c]	TWA[b]	STEL[c]
Acetone	250 ppm	750 ppm	1000 ppm	750 ppm	1000 ppm
n-Butyl acetate	150 ppm	150 ppm	200 ppm	150 ppm	200 ppm
Cadmium	lowest feasible concentration (0.01 mg/m^3 limit of quantitation)	0.2 mg/m^3 as an 8 hour time weighted-average 0.6 mg/m^3 as a ceiling		0.05 mg/m^3	
Chromium compounds with a valence of 2 or 3	0.5 mg/m^3	0.5 mg/m^3		0.5 mg/m^3	
Hexavalent Chromium	0.001 mg/m^3	1 mg/10 m^3 as a ceiling		0.05 mg/m^3	
Ethyl acetate	400 ppm	400 ppm		400 ppm	
Isopropyl alcohol	400 ppm twa 800 ppm Ceiling	400 ppm	500 ppm	400 ppm	500 ppm
Hexamethylene diisocyanate (HDI monomer)	5 ppb twa[28] 20 ppb Ceiling			5 ppb	
Lead	Less than 0.1 mg/m^3 so that blood lead levels remain below 0.06 mg of lead per 100 grams of hole blood.	50 μg/m^3 for an 8-hour day[28]		0.15 mg/m^3	
Particulate (not otherwise regulated) total respirable		 15 mg/m^3 5 mg/m^3		 10 mg/m^3 5 mg/m^3	
Toluene	100 ppm TWA 200 ppm Ceiling	100 ppm	150 ppm	100 ppm	150 ppm
Trimethyl benzene		25 ppm		25 ppm	
Xylene	100 ppm TWA 200 ppm Ceiling	100 ppm	150 ppm	100 ppm	150 ppm

[a]TWA - Time-Weighted Average based upon a 10 hour day, 40 hour work week for NIOSH Recommended Exposure Limit.
[b] TWA - 8-hour Time-Weighted Average.
[c] STEL - Short-Term Exposure Limit.

consider the feasibility of controlling exposures in various industries where the agents are used; the NIOSH RELs, by contrast, are based primarily on concerns relating to the prevention of occupational disease. ACGIH Threshold Limit Values (TLVs) refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. ACGIH states that the TLVs are guidelines. The ACGIH is a private, professional society. It should be noted that industry is legally required to meet only those levels specified by OSHA PELs.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal eight to ten hour workday. Some substances have recommended short-term exposure limits or ceiling values that are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures.

Generally, spray painters are exposed to multiple solvents. To evaluate whether the total solvent exposure is excessive, a combined exposure, C_E, is computed:

$$C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots + \frac{C_n}{L_n} \qquad (1)$$

Where:

C = Exposure to an individual contaminant, and;

L = The lowest exposure limit for the corresponding contaminant listed in Table 1.

When the value of C_E is less than 1, the combined exposure is believed to be acceptable.

EVALUATION PROCEDURES

The objective of this site visit was to obtain an appreciation of the ventilated sanders' ability to control worker exposure to sanding dust. To evaluate the effectiveness of the Hutchins sanders' ventilation, worker air contaminant exposures were measured. The exhaust airflow volume of the Hutchins sanders were measured.

At this autobody shop, autobody spray painting is done outside of a spray painting booth when less than a pint of paint is used. Air sampling was done to evaluate whether this restriction keeps worker air contaminant exposures below the limits specified in Table 2.

Air Contaminant Exposure Monitoring

The worker's total particulate exposure was measured using NIOSH Method 0500.[30] In this method, a known volume of air is drawn through a preweighed PVC filter at a flow rate of 3.5 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 per cubic meter of air. After weighing, the filters were analyzed for lead, cadmium, and chromium. The filters were digested using NIOSH Method 7300 and were diluted to 25 mL. Then a simultaneous scanning inductively coupled plasma emission spectrometer was used to analyze the samples for lead, cadmium, and chromium.

Material safety data sheets were used to identify the major organic solvents which may be present during spray painting. Exposures to these solvents were measured: acetone, n-butyl acetate, ethyl acetate, isopropyl alcohol, n-butyl alcohol, toluene, and xylene. Exposure measurements were made by placing charcoal tubes (SKC lot 120) in a charcoal tube holder and mounting the charcoal tube holder on the worker. Tubing connects the outlet of the charcoal tube holder to a personal sampler pump (Model 200, Dupont Inc.) that draws air through the charcoal tube at 200 cm^3/min. The collected solvents are desorbed from the charcoal using carbon disulfide and the solvents are quantitated using a gas chromatograph equipped with a flame ionization detector. NIOSH Methods 1300, 1400, 1450, 1401, and 1501 were used with some modifications.[31] The modifications are listed below:

Desorption Process:	Thirty minutes in 1.0 milliliter of carbon disulfide with 0.5 microliter ethyl benzene/ml CS_2 as an internal standard and 1 percent n-propyl alcohol as a desorbing aid.
Gas Chromatograph:	Hewlett-Packard Model 5890 equipped with a flame ionization detector.
Column:	30m x 0.32mm fused silica capillary coated, internally with 0.5 μm of DB-EAD.
Oven Conditions:	35°C for five minutes, temperature increase at a rate of 5°C/minute until a temperature of 75°C is reached. The latter temperature is held for two minutes.

In addition to collecting personal samples for metals, particulates, and organic solvents, area samples were collected away from the operation of interest. When sampling was done in the autobody repair area, area samples were collected 5-10 feet away from the worker. In the autobody preparation area, the area samples were collected at the location noted in Figure 1.

Video Exposure Monitoring

Video exposure monitoring was used to study in greater detail how specific tasks affect the workers' exposure to air contaminants.[32,33] Worker exposures were monitored with a direct reading instrument, and its analog output was recorded with a data logger. Workplace activities were simultaneously recorded on videotape. The analog output of the real-time instruments was connected to a data logger (Rustrak Ranger, Gulton, Inc., East Greenwich, RI). When the data collection was completed, the data logger was downloaded to a portable computer (Compaq Portable III, Compaq Computer Corporation, Houston, TX) for analysis.

During vehicle preparation operations, the Hand-held Aerosol Monitor (HAM, PPM Inc., Knoxville, KY) was used to measure relative air contaminant concentrations during sanding operations. The aerosol scatters the light emitted from a light emitting diode. The scattered light is detected by a photomultiplier tube. The analog output of the HAM is proportional to the quantity of the scattered light detected by a photomultiplier tube. Because the calibration of the HAM varies with aerosol properties such as refractive index and particle size, the analog output of the HAM is viewed as a measure of relative concentration. An Aircheck personal sampling pump (Aircheck, SKC Inc, Eighty Four, PA) was used to draw air through the HAMs sensing chamber at a rate of 3.5 lpm.

During spray painting, a Microtip HL200 (PHOTOVAC Inc, Thornhill, Ontario) was used to monitor worker solvent exposure. 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, this instrument also is used as a measure of relative concentration. Because of fire safety considerations, this instrument was located outside of the spray painting area. Teflon tubing (0.125 inside diameter, 45 feet long, Alltech Associates, Deerfield, IL) 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 Microtip then sampled the air in this glass tee.

Ventilation Measurements

The exhaust flow rates from the ventilated sanders were measured in the apparatus illustrated in Figure 3. The exhaust flow rate was measured when the sanders were off, when they were on (but not sanding), and when they were

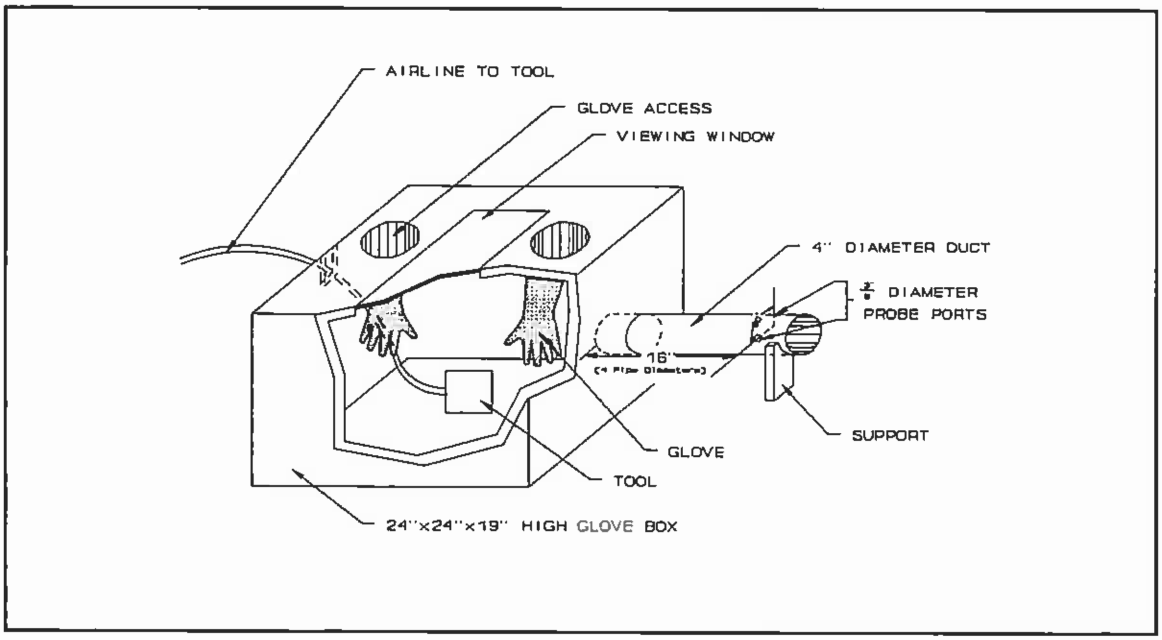

Figure 3. Apparatus for measuring the exhaust airflow of ventilated tools.

sanding metal on the bottom of the apparatus. The air velocity in the exhaust duct was measured using a hot wire anemometer (Model 1040 Digital Air Velocity Meter, Kurz, Carmel Valley, CA). The exhaust flow rate was calculated as the product of the duct's cross sectional area and 0.9 times the air velocity at the duct's centerline.

Exhaust fans for the spray painting booth and the small parts spray painting booth were located on the roof of the autobody shop. The area through which the fan discharges the air and the exhaust velocity were measured. From this data, the exhaust volume of each fan was estimated as the product of the area and exhaust velocity.

RESULTS

Ventilation Measurements

Tables 3 and 4 summarize the ventilation measurements. The sanders' ventilation rates are summarized in Table 3. Turning the compressed air on for the 6-inch sander and the in-line sander decreased the exhaust flow rates because the compressed air is discharged into the vacuum hose. The flow rates during sanding appeared to decrease about 20 percent pending the force applied to the sander.

The small parts spray painting booth has no provisions for makeup air. As a result, its exhaust flow rate decreased dramatically when the doors to this booth room were closed. This booth is exhausted by two fans which move about 650 cfm. However, one fan also exhausts air from a paint mixing area near the small parts spray painting booth. When this booth's door is closed, the air will follow the path of least resistance to the fan, which is apparently through the exhaust grates in the paint mixing area. Closing this door increases the paint mixing area flow rate from 130 to 630 cfm and decreases the exhaust flow from the small parts spray painting booth from 1200 to 400 cfm.

Table 3

Sander Ventilation Rates

Type of Sander	Exhaust Flow Rate (cfm)		
	Compressed Air Off	Compressed Air On	Sanding on Sheet Metal
6-inch sanding pad	67	47	35
9-inch sanding pad	68	68	45
in-line sander	18	14	15

Table 4

Exhaust Ventilation Rates Measured on the Roof

Exhaust Flow Measurement	Exhaust Flow Rate (cfm)	
	Measured	Recommended
Central vacuum system	310	NA
Cross draft spray painting booth. The recommended flow rate is based the booths cross sectional area (14 feet wide and a height of 12.6 feet). For such booths, ACGIH recommends an exhaust volume of 50 cfm/ft^2 of cross sectional area.	11800	17500 (OSHA)[34] 8750 (ACGIH)[35]
Car repair area, east side	6880	NA
Car repair area, west side	2650	NA
Paint preparation area, local exhaust ventilation at paint mixing area. The exhaust volume is affected by the small parts spray painting booth doors: open closed	 130 630	NA
Small parts spray painting booth; doors open doors closed	1200 425	17500 (OSHA) 8750 (ACGIH) 1600 (Oregon)[36]
Area for autobody preparation and painting of small areas on the car. The recommended exhaust rate is based upon the assumption the one pint of toluene is evaporating in a ten minute period. In actual practice, the paints used are a mixture of organic solvents, and these paints contain solid materials which do not evaporate.	3950	3800 (ACGIH)[37]

NA - Not Available.

Air Sampling Results

The results of individual air samples are presented in Appendices A and B. The concentration of particles in the air was computed by subtracting the average weight change of blank filters from the weight change of the sample filters and dividing this difference by the sample volume. For some samples, the individual filters actually lost more weight than the average of the blank filters; so, these concentrations are labelled with an "n" to indicate that the computed concentration is less than zero. Although individual sampling results did not provide insight into the exposures encountered during sanding and spray painting operations, the sum filters weight changes and sample volumes were used along with the blank correction to compute a time-weighted average concentration. As described in Appendix C, the standard deviation of the blank filters was used to estimate a limit of detection (LOD) and a limit of quantitation (LOQ) for these time-weighted average concentrations listed in Table 5.

Table 5

Summary of Particulate Air Sampling Results

Operations for Which Particulate Exposures were Monitored	Number of Samples	Concentration+ (mg/m^3)
Spraying parts in large spray painting area	4	6.9
Spray painting small area on a car in the large spray painting area	3	2.1
Spray painting parts in small parts spray painting booth	1	25.0
Spray painting a car in a booth	1	4.6
Sanding with a ventilated 6-inch sander	3	1.5
Sanding with a ventilated in-line sander	4	0.3*
Sanding with an unventilated in-line sander	1	2.1*

+ - These are short-term, time-weighted average concentrations.

* - The result is between the estimated limits of qualitation and quantitation. See Appendix C for details.

Most of the short-term exposures listed in Table 5 were below the exposure limits listed in Table 2. However, in Table 5, one short-term air sample for particulates revealed a concentration of 24 mg/m^3 for a 17 minute period. Because the OSHA PEL for an eight hour time-weighted average exposure is 15 mg/m^3 and the worker had other duties which involve particulate exposures which were well below 15 mg/m^3, this worker's particulate exposure over the an eight hour period is probably less than 15 mg/m^3. This study was not conducted specially to evaluate compliance with OSHA PELs and eight hour time-weighted average samples were not collected. However, this single sample indicates a need to improve ventilation in the small parts spray painting booth. Recommendations for improving the ventilation in this booth are discussed later.

In addition to analyzing the filters for total amount of particulate in the air, the filters were analyzed for lead, cadmium, and chromium. The amount of these metals on the filters was less than the detection limit. The limits of detection for cadmium, chromium, and lead were respectively 1, 1, and 2 μg per sample.

Solvent exposure during spray painting operations were generally low and exposures to individual solvents are presented in Appendix B. Table 6 shows the results of computing the combined exposure, C_E. This computation assumes that the exposures take place over an eight hour day. In reality, the workers only spend a fraction of each day spray painting. The results in Table 6 indicate that, under the conditions present during testing, exposures are within permissible limits.

Because the composition of paints varies, one cannot tell whether the use of a high velocity, low pressure (HVLP) spray gun actually reduces worker solvent exposure. However, one of the highest and one of the lowest combined solvent exposures occurred with a conventional spray painting gun.

Video Exposure Monitoring

The results presented in Figures 4 and 5 show the output of HAMs while the worker was using the in-line sander to smooth body filler which had been applied to a door. The effectiveness of the ventilated sanders was demonstrated by comparing dust exposures while using an unventilated in-line sander. As shown in Figure 4, the worker's exposure increased dramatically when the nonventilated sander was in use. Based upon the HAMs response, the use of the ventilated sander apparently decreased the worker's particulate exposure by a factor of about 8. The statistical analysis presented in Appendix D shows that decrease was statistically significant.

Table 6

Combined Solvent Exposures

Operation	Spray Painting Gun	Date	Sample Start Time	Sample Stop Time	C_E
Spray painting small area on car outside of a booth	HVLP	9/16	11:00	11:25	0.18
Spray painting small area on car outside of a booth	HVLP	9/16	13:10	13:35	0.69
Spraying parts within small parts spray painting booth	HVLP	9/17	9:25	9:42	0.31
Spraying painting car in large booth	HVLP	9/17	14:42	15:45	0.05
Spray painting parts outside of a booth	HVLP	9/17	10:56	11:05	0.07
Spray painting small area on car outside of a booth	HVLP	9/18	9:07	9:35	0.16
Spray painting parts outside of a booth with conventional gun	Conven-tional	9/18	11:21	11:27	0.49
Spray painting parts outside of a booth with a conventional spray painting gun	Conven-tional	9/19	Sampling times obtained from pump's built-in timer		0.10
Spray painting parts outside of booth	HVLP	9/19	Sampling times obtained from pump's built-in timer		0.14

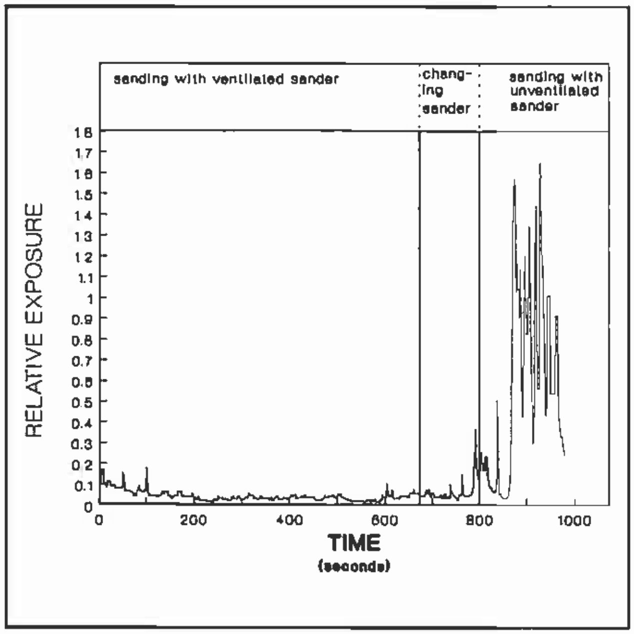

Figure 4. Sanding with a ventilated and unventilated in-line sander.

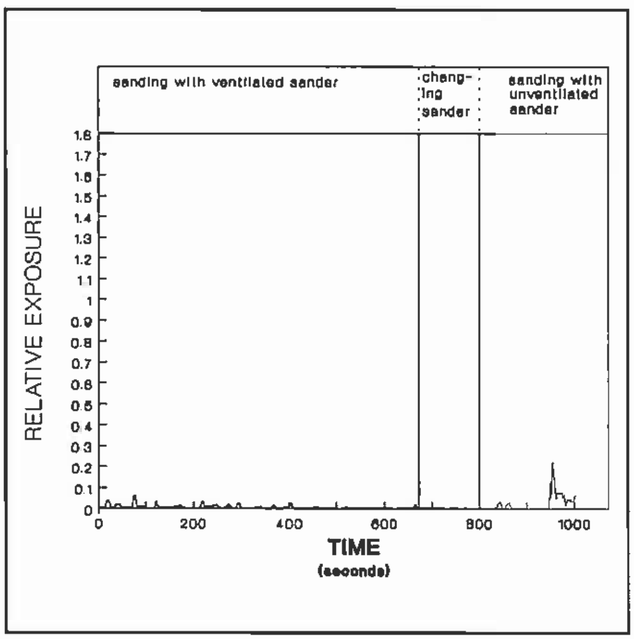

Figure 5. Background concentrations measured while data in Figure 4 was taken.

While a worker was sanding quarter panels with a 6-inch sander, HAMs were used to monitor the worker's particulate exposure and the background concentration. This result is presented in Figure 6. This sander was ventilated. The fact that the background measurement is higher than the measurement on the worker is probably due to a slight difference between instruments.

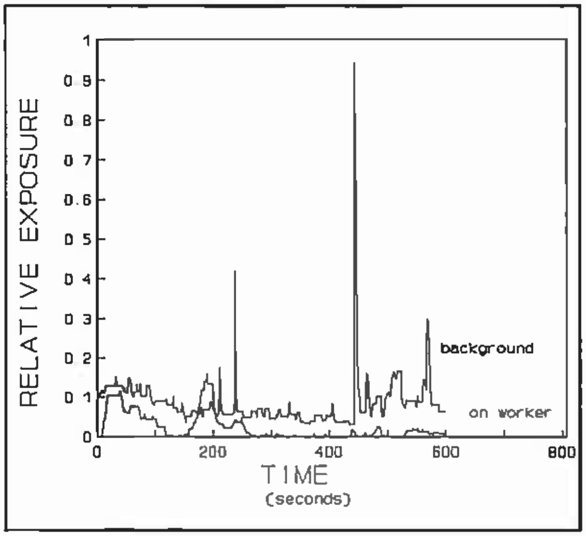

Figure 6. Output of a HAM while worker was sanding auto parts using a 6-inch ventilated sander.

While a worker spray painted two body panels using an HVLP spray painting gun, his exposure to solvent vapors was monitored with a Microtip. Its output was recorded using a data logger, and the worker's activities were videotaped. Figure 7 shows the response of the Microtip to organic vapors. Viewing of the videotape reveals that spray painting outside of a booth disperses the overspray throughout the work area. While spray painting, the worker moved around the panel and periodically returned to his bench which was 5-10 feet from where the spray painting was being done. A statistical analysis presented in Appendix D found that the worker's exposure did not vary with his location. The worker's exposure was observed to increase with spraying time and decrease with length of time after spraying had ceased.

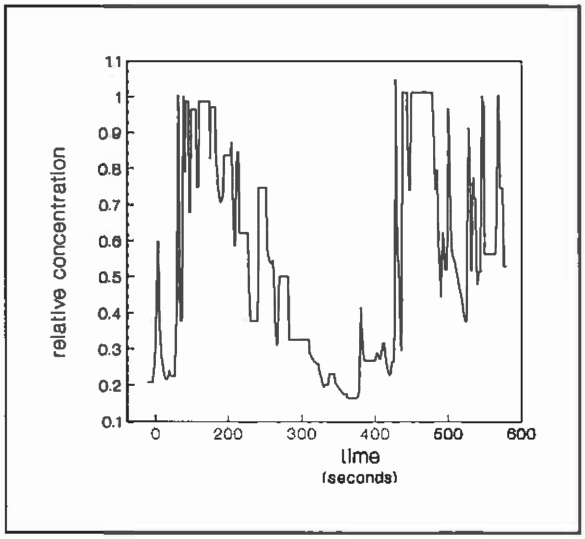

Figure 7. Response of Microtip to solvent vapors generated by spray painting autobody parts in large painting area.

DISCUSSION

The video exposure monitoring data suggests that the ventilated sanders control much of the aerosol generated during sanding. Based upon the limits of detection in Table 5, the total dust samples indicate that the worker's particulate exposure is less than 1-2 mg/m^3. The HAM readings taken when the 6-inch sander and the in-line sander were used suggest that the worker's respirable particulate exposure during sanding may actually be less than 0.2 to 0.1 mg/m^3. Typically, the concentration of particles smaller than 10 μm in the ambient environment is generally less than 0.1 mg/m^3 and is typically between 0.02 and 0.06 mg/m^3.[38] Because aerosol photometers are relatively insensitive to particles larger than 10 μm, aerosol photometer measurements do not provide much insight as to whether the sanders are capturing the larger particles which have most of an aerosol's mass. Although the available data indicates that these sanders apparently do provide a degree of dust control, the data does not provide a complete understanding of the abilities and limitations of devices to control worker dust exposure during sanding. Thus, there is a need for further evaluation.

The workers liked the installation of the ventilated sanders. The retractors kept the exhaust hoses and compressed air lines at a convenient location. Because of this convenience, these sanders were always used with the exhaust hose. In other shops visited by the survey team, the hoses were stored separately from the tools. As a result, workers had to take time to find the exhaust hoses, and this lack of convenience results in some sanding without ventilation.

Airflow Recommendations for the Spray Painting Booths

Table 4 lists exhaust volume recommendations for different sources for the spray painting booth and the small parts spray painting room. In the spray painting booth, the worker's particulate exposure and solvent exposure were below the exposure limits listed in Table 2. Although the spray painting booth's flow rates are below the flow rates specified in OSHA standard 29 CFR 1910.94(c), ventilation standards are enforced only when there is a violation of the OSHA PELs specified in Table 2. The flow rate is well above that recommended by ACGIH. Furthermore, the state of Washington's Division of Safety and Health considers these standards to be recommendations to employers.[39] As stated in this manual: "Ventilation within this category (Health-Related Ventilation Standards)" will be considered adequate when the concentration of air contaminants to which employees are exposed does not exceed recognized hazardous levels." Based on the limited sampling and evaluation, there is no urgency, at present, to change the spray painting booth's flow rate.

In the small parts spray painting booth, the worker's particulate exposure was 24 mg/m^3 indicating that the ventilation in this room needs to be improved. At the time of the study, closing the doors caused the airflow out of this room to drop from 1200 cfm to 400 cfm. Clearly, the worker's exposure to total particulate could be reduced by introducing makeup air into this room. The state of Oregon specifies at least 30 air changes per hour for spray painting rooms.[36] This results in a recommended air flow of 1600 cfm of air flow for spraying rooms. At a ventilation rate of 1600 cfm, applying less than a pint of paint to autobody parts in a ten minute period would result in exposures below 100 ppm (the REL for solvents such as xylene). This assumes that half of the paint is a volatile organic solvent such as xylene. Furthermore, restricting the amount of paint used should also result in lower particulate exposures. If this recommendation is followed, air sampling should be done to document the exposures which result.

Generally, a face velocity of 100 fpm is specified to control the paint overspray at spray painting booths and hood.[34] However, the American Conference of Governmental Industrial Hygienist's ventilation manual specifies 50 fpm air velocity in an automotive spray painting booth when the cross sectional area is greater than 150 square feet and 100 fpm when the cross sectional area is less than 150 square feet.[35] When a cross draft automotive spray painting booth with a face velocity of 100 fpm was used to spray paint an entire car, worker total particulate exposures ranged between 4 and 16 mg/m^3, and solvent exposures were below NIOSH recommended exposure limits.[40] This suggests that if the cross draft spray painting booth were used for spray painting small parts instead of the small parts spray painting booth, the worker's particulate exposure should be reduced. Because this shop already has a cross draft spray painting booth, it probably does not make sense to convert the small parts spray painting booth to a shorter version of a cross draft spray painting booth.

CONCLUSIONS

The ventilated Hutchins sanders studied at this autobody shop appear to be useful for controlling worker exposure to aerosols generated during sanding. The available data indicate that the workers' particulate exposures are less than 1-2 mg/m^3 when the ventilated sanders are in use.

For the conditions observed in this study, spray painting outside of a spray painting booth or the small parts spray painting booth did not cause excessive solvent or particulate exposures when less than a pint of paint was used. However, spray painting in the small parts spray painting booth did result in a short-term exposure to a spray painting mist of 24 mg/m^3 for a 17 minute period. This single sampling result does indicate that the ventilation in the small parts spray painting booth is inadequate. This exposure could be minimized by providing makeup air for the small parts spray painting room.

REFERENCES

1. IARC [1989]. IARC monographs on the evaluation carcinogenic risks to humans, some organic solvents, resin monomers and related compounds, pigments, and occupational exposures in paint manufacture and painting. Vol. 47. Lyon, France: International Agency for Research on Cancer.

2. Seguin P, Allard A, Cartier A, Malo JL [1987]. Prevalence of occupational asthma in spray painters exposed to several types of isocyanates, including polymethylene polyphenylisocyanate. J Occup Med 29:340-343.

3. NIOSH [1978]. Criteria for a recommended standard: occupational exposure to diisocyanates. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 78-215.

4. Charles J, Bernstein A, Jones B, Jones D, Edwards J, Seal R, Seaton A [1976]. Hypersensitivity pneumonitis after exposure to isocyanates. Thorax 31:127-136.

5. Hardy HL, Devine JM [1979]. Use of organic isocyanates in industry - some industrial hygiene aspects. Ann Occup Hyg 22:421-427.

6. Belin L, Hjortsberg U, Wass U [1981]. Life-threatening pulmonary reaction to car paint containing a prepolymerized isocyanate. Scand J Work Environ Health 7:310-312.

7. Mobay [1987]. Health and safety information - hexamethylene diisocyanate (HDI) based polyisocyanates. Pittsburgh, PA: 11 pp.

8. NIOSH [1987]. Current Intelligence Bulletin 48: organic solvent neurotoxicity. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 87-104.

9. Elofsson S, [1980]. Exposure to organic solvents -- a cross-sectional epidemiologic investigation on occupationally exposure car and industrial spray painters with special reference to the nervous system. Scand J Work Environ Health 6:239-273.

10. NIOSH [1971]. Occupational diseases-a guide to their recognition. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-181.

11. Proctor NH, Hughes JP [1978]. Chemical hazards of the workplace. New York, NY: J.P. Lippincott Co.

12. ACGIH [1986]. Documentation of the threshold limit values. 5th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

13. NIOSH [1977]. Occupational diseases, a guide to their recognition. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, Revised Ed., DHEW (NIOSH) Publication No. 77-181.

14. NIOSH/OSHA [1981]. Occupational health guidelines for chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-123.

15. Hammond P, Beliles R [1980]. Metals. In: Doull J, Klassen C, Amdur M, eds. Casarett and Doull's Toxicology. 2nd ed. McMillan Publishing Company.

16. Hathaway G, Proctor N, Hughes J, Fischman M [1991]. Proctor and Hughes' Chemical Hazards of the Workplace. In: Van Nostrand Reinhold. New York, NY.

17. Webb M [1975]. Cadmium. Br Med Bull 31:246-50.

18. NIOSH [1984]. Current Intelligence Bulletin 42: Cadmium. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 84-116.

19. NIOSH [1975]. Criteria for a recommended standard: occupational exposure to chromium (VI). Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-129.

20. Doull J, Klaassen CD, Amdur MD [1980]. Casarett and Doull's Toxicology. 2nd ed. New York, NY: MacMillan Publishing Co. Inc.

21. NIOSH [1972]. Criteria for a recommended standard: occupational exposure to lead. U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 78-158.

22. NIOSH/OSHA [1988]. Occupational health guidelines for chemical hazards. In: NIOSH/OSHA. Occupational safety and health guideline for inorganic Lead. Cincinnati, OH: U.S. Department of Health and Human Services Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-123.

23. Kristensen TS [1989]. Cardiovascular diseases and the work environment--a critical review of the epidemiologic literature on chemical factors. Scand J Work Environ Health 15:245-264.

24. Pirkle JL, Schwartz J, Landis JR, Harlan WR [1985]. The relationship between blood lead levels and blood pressure and its cardiovascular risk implications. Am J Epidemiol 121(2):246-58.

25. NIOSH [1990]. NIOSH pocket guide to chemical hazards. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 90-117.

26. CFR. Code of Federal Regulations, [29 CFR 1910.1000 (1989)]. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

27. ACGIH [1990]. 1990-1991 Threshold limit values for chemical substances and physical agents and biological exposure indices, Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

28. CDC (Centers for Disease Control) [1988]. NIOSH recommendations for occupational safety and health standards. MMWR Supplement 37:S-7.

29. CFR. Code of Federal Regulations [29 CFR 1910.1025 (1989)]. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

30. NIOSH [1984]. Nuisance dust total, method 0500. In: NIOSH Manual of Analytical Methods, 3rd ed., with supplements 1, 2, 3, and 4. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No 84-100.

31. NIOSH. Method of Analytical Methods, 3rd ed., with supplements 1, 2, 3, and 4. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, NIOSH Publication No 84-100.

32. Gressel MG, Heitbrink WA, McGlothlin JD, Fischbach TJ [1988]. Advantages of real-time data acquisition for exposure assessment. Appl Ind Hyg 3(11):316-320.

33. Gressel MG, Heitbrink WA, McGlothlin JD, Fischbach TJ [1987]. Real-time, integrated, and ergonomic analysis of dust exposure during manual materials handling. Appl Ind Hyg 2(3):108-113.

34. CFR. Code of Federal Regulations [29 CFR 1910.94(c)]. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

35. ACGIH [1992]. Plate VS-75-04, Large drive-through spray paint booth. In: Industrial Ventilation-A Manual of Recommended Practice, 21st ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists

36. Janko M, McCarthy K, Fajer M, Raalte J [1992]. Occupational exposure to 1,6-hexamethylene diisocyanate-based polyisocyanates in the state of oregon. Am Ind Hyg Assoc J 53:331-338.

37. ACGIH [1992]. Industrial ventilation - a manual of recommended practice. Cincinnati, OH: American Conference of Governmental Industrial Hygienists

38. U.S. EPA [1991]. National Air Quality Emissions Trends Report, 1989. Research Triangle Park, NC: U.S. Environmental Protection Agency.

39. State of Washington, Department of Labor and Industries, Division of Industrial Safety and Health [1987]. Industrial hygiene field operations manual. Olympia, WA: Document F416-133-412.

40. O'Brien DM, Hurley DE [1981]. An evaluation of engineering control technology for spray painting. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 81-121.

41. Keith L, Crummett W, Deegan J, Libby R, Taylor J, Wentler G [1983]. Principals of environmental analysis. Anal Chem 55:2210-2218.

42. SAS Institute Inc. [1988]. The GLM procedure. In: SAS/STAT User's Guide Release 6.03. Cary, NC: pp. 549-640.

APPENDIX A

Particulate Concentrations During Sanding and Spray Painting

Description	Date	Type	Time		Time	Mass	Concentration
			Start	Stop	(min)	(mg)	(mg/m³)
In office by Sue's Desk	9/19	a	14:30	16:11	230	0	0.06
Northwest corner of parking lot	9/19	a	14:30	16:11	236	-0.02	0.03
Near detailing and cleanup station	9/19	a	14:30	16:11	231	0.08	0.16
Sanding with 6-inch sander	9/16	p	13:41	14:00	18	0.11	2.5
	9/16	A	13:41	14:00	18	-0.02	0.45
Sanding with 6-inch sander	9/17	p	12:55,14:20	13:02,14:26	21	0.01	0.80
	9/17	a	12:55,14:20	13:02,14:26	24	-0.03	0.22
Sanding with 6-inch sander	9/17	p	14:05	14:14	9	-0.01	1.2
	9/17	a	14:05	14:14	11	-0.05	n
Sanding panels with in-line sander	9/17	A	9:04	9:40	36	-0.03	0.14
	9/17	p	9:04	9:40	36	-0.03	0.14
Sanding door with unventilated in-line sander	9/19	p	Sampling times obtained from pump's built-in timer		10	0.05	2.8
Sanding with in-line sander	9/19	p	7:55	8:25	30	-0.03	0.17
	9/19	A	7:55	8:25	30	0.03	0.74
Sanding with in-line sander	9/19	p	8:55	9:18	27	-0.04	0.09
	9/19	a	8:55	9:18	27	-0.04	0.09
Sanding with in-line sander	9/18 -19	A	9:00 9:35	9:10 9:50	25	-0.05	n
	9/18 -19	p	9:00 9:35	9:10 9:50	25	0.03	0.89

Appendix A (continued)

Description	Date	Type	Time		Time	Mass	Concentration
			Start	Stop	(min)	(mg)	(mg/m^3)
Spray painting car outside of booth with HVLP spray painting gun	9/16	p	13:10	13:35	26	0.18	2.5
	9/16	A	13:10	13:35	25	0.03	0.89
Spray painting car outside of booth with HVLP spray painting gun	9/16	p	11:00	11:25	23	0.22	3.3
	9/16	A	11:00	11:25	23	0	0.6
Spray painting parts outside of booth with an HVLP spray painting gun	9/17	p	10:56	11:05	9	0.01	1.8
	9/17	a	10:56	11:05	9	-0.03	0.58
Spray painting car in cross draft spray painting booth with an HVLP spray painting gun	9/17	p	14:42	15:25	45	0.68	4.6
Spray painting parts in the small parts spray painting booth with an HVLP spray painting gun	9/17	p	9:25	9:42	17	1.46	25
Spray painting parts outside of a booth with conventional spray painting gun	9/18	p	11:21	11:27	6	0.14	8.9
	9/18	a	11:21	11:27	8	-0.06	n
Spray painting car outside of booth with an HVLP spray painting gun	9/18	p	9:05	9:35	25	0.01	0.66
	9/18	a	9:05	9:35	24	-0.03	0.22
Spraying painting parts outside of booth with a conventional spray painting gun	9/19	a	Samples were collected between 10:00 and 12:00. The actual sample time was not recorded. The length of the sampling period was obtained from pump's built-in timer.		17	-0.04	0.14
	9/19	p			17	0.27	5.4
Spray painting parts outside of booth with an HVLP spray painting gun	9/19	a			10	0	1.4
	9/19	p			10	0.16	5.9
field blank						-0.04	
field blank						-0.05	
field blank						-0.04	
field blank						-0.05	

Appendix A (continued)

Description	Date	Type	Time		Time	Mass	Concentration
			Start	Stop	(min)	(mg)	(mg/m^3)
field blank						-0.06	
field blank						-0.06	
field blank						-0.04	
		mean weight change of blank filters (this is the blank correction)				-0.05	
		standard deviation of weight change for blank filters				0.01	

APPENDIX B

Concentration of Organic Vapors in Parts Per Million During Spray Painting

Job Description	Date	Type	Times Start	Times Stop	Acetone	Butyl Acetate	Ethyl Acetate	Isopropyl Alcohol	n-butyl Alcohol	Toluene	Xylene	Tri-Methyl Benzene
Spray painting car outside of booth with HVLP spray painting gun	9/16	p	11:00	11:25	4	nr	nr	5	1	10	2	nr
	9/16	a	11:00	11:25	LT 1.8	nr	nr	LT 0.9	LT 0.7	LT 0.6	LT 0.5	nr
Spray painting car outside of booth with HVLP spray painting gun	9/16	p	13:10	13:35	6	nr	LT 0.06	9	24	14	2	nr
	9/16	a	13:10	13:35	LT 1.7	nr	LT 0.06	LT 0.08	LT 0.07	1	LT 0.05	nr
Spray painting parts in small parts spray painting booth with HVLP spray painting gun	9/17	p	9:25	9:42	LT 2.5	5	LT 0.08	nr	nr	13	9	1
Spray painting parts outside of spray painting booth with HVLP spray painting gun	9/17	p	10:56	11:05	LT 4.7	nr	nr	nr	nr	5	1	nr
	9/17	a	10:56	11:05	LT 4.7	nr	nr	nr	nr	LT 1.5	LT 1.2	nr
Spray painting car in the cross draft spray painting booth with HVLP spray painting gun	9/17	p	14:42	15:45	1	nr	nr	nr	nr	2	2	nr
Spraying parts in open with conventional gun	9/18	p	11:21	11:27	15	nr	nr	nr	nr	19	15	nr
	9/18	a	11:21	11:27	LT 1.8	nr	nr	nr	nr	LT 2	LT 0.5	nr

Appendix B (continued)

Job Description	Date	Type	Times Start	Times Stop	Acetone	Butyl Acetate	Ethyl Acetate	Isopropyl Alcohol	n-butyl Alcohol	Toluene	Xylene	Tri-Methyl Benzene
Spray painting car outside of a booth with HVLP spray painting gun	9/18	p	9:07	9:35	3	nr	nr	nr	nr	11	4	nr
	9/18	a	9:07	9:35	LT 2	nr	nr	nr	nr	1	LT 0.5	nr
Spray painting parts outside of booth with a conventional gun	9/19	p	Samples were collected between 10:00 and 12:00. The actual sample time was not recorded. The length of the sampling period was obtained from pump's built-in timer.		2	nr	nr	2	1	1	5	nr
	9/19	a			LT 2	nr	nr	LT 1	LT 1	LT 1	LT 0.7	nr
Spray painting parts outside of a booth with a HVLP spray painting gun	9/19	p	Samples were collected between 10:00 and 12:00. The actual sample time was not recorded. The length of the sampling period was obtained from pump's built-in timer.		LT 4	nr	nr	4	LT 1.6	8	5	nr
	9/19	a			LT 4	nr	nr	LT 2	LT 1.6	LT 1	LT 1.2	nr

Abbreviations:

a - area sample; p - personal sample; LT - less than (indicates that the substance was not detected); and,
nr - no result, sample was not analyzed for this substance because substance was not reported on material safety data sheet.

APPENDIX C

Computation of Limits of Detection and Quantitation

In Appendix A, the weight change of many of the filters is actually negative. However, after correcting for the weight change of the field blanks (unused filters), positive values of concentrations were computed. In Appendix A, four of the seven personal samples for sanding operations resulted in filters which lost less weight than the average of the blank filters. After correction for the weight change of the blank filters, individual values of concentrations are computed to have positive values. Because the uncertainty in these individual concentration values is greater than ±20%, the individual values of concentration are not very meaningful. In order to obtain some information about the exposures during the operations listed in Table 5, individual sampling results can be combined to compute a single time-weighted average concentration for each operation listed in Table 5. This is done dividing the sum of the individual filter weight gains (after correction for the blank) by the sum of the individual sample volumes. From the sums, a single value of concentration is computed. From the standard deviation of the field blanks (s_b), the uncertainty in the time-weighted average concentration can be evaluated. The development of the formulas for estimating the standard deviation sum of the filter weight gains is presented below.

In order to compute a time-weighted average concentration, the sum of the filter weight gains, m_{total}, is computed:

$$m_{total} = \sum_{i=1}^{k} (m_i - \bar{b}) \tag{1}$$

Where:

k = number of samples which are being summed, and;

$\bar{b}$ = mean weight change of field blanks.

Since the members of sample of filter weights, $\{m_i\}$, are assumed to have equal variances, σ_m^2 , and are statistically independent of each other and of $\bar{b}$, the variance of m_{total} is given by:

$$\sigma_{m_{total}}^2 = k\sigma_m^2 + k^2 \frac{\sigma_b^2}{n} \tag{2}$$

Where:

σ_b^2 = the variance assumed for any blank filter, and;

n = number of blank filters used to estimate the mean weight change of the blank filters.

Note: the result in equation 2 follows from the general formula for the variance of a linear combination of random variables, e.g., u = ar + ds where a and d are constants and r and s are random variables:

$$\sigma_u^2 = a^2\sigma_s^2 + d^2\sigma_r^2 + 2ad\sigma_{rs}$$
$$= a^2\sigma_s^2 + d^2\sigma_r^2 + 2ad\rho_{sr}\sigma_s\sigma_r$$
$$= a^2\sigma_s^2 + d^2\sigma_r^2 \quad if \ \rho_{rs} = 0$$
$$= \sigma_s^2(a^2 + d^2) \quad if \ \sigma_s = \sigma_r$$

where

$\rho_{rs} = \rho_{sr}$ = the correlation of r and s

$$or \ \sigma_u^2 = a^2\sigma_s^2 + d^2ad\sigma_r^2 + 2ad\sigma_r\sigma_s \quad if \ \rho_{rs} = 1$$
$$= \sigma_s^2(a^2 + d^2 + 2) \quad if \ \sigma_s = \sigma_r$$

These expressions were generalized to the sum of the k terms m_i, as i ranges from 1 to k, and k times the average blank filter weight corrections when equation 1 is expanded. These k+1 terms are statistically independent and, therefore, all pairwise correlations are zero. The term involving k^2 in equation 2 occurs because the average blank weight is multiplied by the constant k in equation 1 when it is expanded.

The term σ_b^2 is the variance of the filter weighing process which is assumed to be the same for any filter whether blank or not. Thus, it is assumed that

$$\sigma_m^2 = \sigma_b^2 \tag{3}$$

Using this assumption, equation 2 may be simplified as follows:

$$\sigma_{m_{total}}^2 = k\sigma_b^2 \ (1 + \frac{k}{n}) \tag{4}$$

Since s_b^2 is used to estimate σ_b^2, the estimated variance for the total weight gain, s_{tot}^2 is computed by substituting s_b^2 in equation 4 to obtain:

$$s_{total}^2 = ks_b^2(1+k/n) \tag{5}$$

Thus, the required estimator for standard deviation for the sum of the filter weight gains is given as:

$$s_{tot} = s_b(k[1+k/n])^{0.5} \tag{6}$$

Then the limits of detection and quantitation can be computed:

$$limit\ of\ detection = \frac{3\, s_{tot}}{total\ volume\ of\ air\ sampled} \tag{7}$$

$$limit\ of\ quantitation = \frac{10\, s_{tot}}{total\ volume\ of\ air\ sampled} \tag{8}$$

The limits of detection (LOD) and quantitation (LOQ) are used to evaluate the quality of environmental data.[41] When the LOD is exceeded, there is a 99 percent probability that an analyte has been measured. When the summed mass does not exceed the LOD, one is uncertain whether these computed concentrations reflect the actual particle collection or the experimental noise in the measurement process. When the LOQ is exceeded, the uncertainty in the measured concentration is less than 30 percent at the 99 percent level of confidence. When the measured concentration is between the LOD and the LOQ, the results are reported although they are known to be imprecise.

APPENDIX D

Statistical Analysis of the Real-time Data

The real-time data collected during the use of the in-line sander and during spray painting was analyzed by regression analysis using the SAS General Linear Models Procedure to determine whether events in the workplace affected relative concentrations, which were literally the analog output of the instruments in volts. After down loading and file conversion, the analog output was imported into a spreadsheet. Each row in the spreadsheet contained the relative concentration at the end of a one second sampling period. A videotape of the worker's activity was viewed and variables were added to describe events in the workplace. For the data taken with the in-line sander, a column was added to describe whether the worker was sanding with a ventilated sander, sanding with an unventilated sander, or not sanding. For the data taken while the worker was spray painting with an HVLP spray painting gun, two columns of explanatory variables were added. One column was coded to describe whether the worker was actually spraying paint. A second column was added to describe the location of the worker relative to the object being sprayed. As schematically illustrated in Figure D1, the worker had five possible locations, away from the object, in front of it, behind it, right side, and left side. After assembling all of the data on a spread sheet, the data was analyzed using the Statistical Analysis System's general linear models procedure.[42]

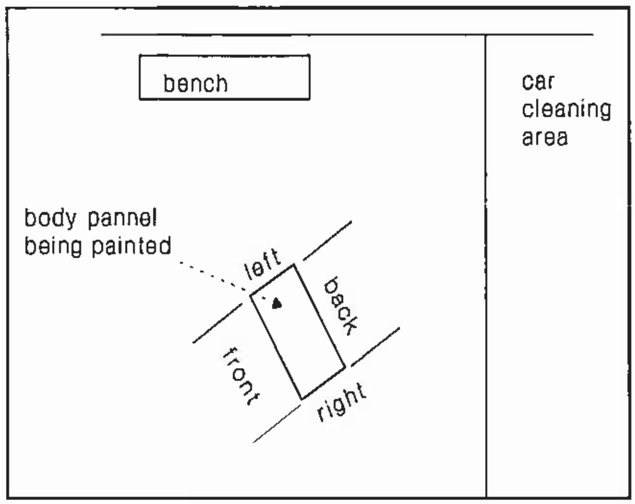

Figure D1. Schematic illustrating the worker's locations during spray painting.

Before conducting the statistical analysis, the logarithm of the relative concentration was computed and this value was termed C in the regression models. Real-time data generally involves autocorrelation which is caused by the dependency of the present value of concentration measurements upon past values of concentration. This causes an understatement of the data's variability and an overstatement of the conclusions which are obtained from the analysis. To minimize these complications, the regression models included prior values of C in the preceding time intervals.

The real-time data collected with the in-line sander was used to fit a model of this form:

$$C = \beta_o + \sum_{k=1}^{9} \beta_k C_k + \beta_{10} A_1 + \beta_{11} A_2$$

Where:

C_j = The logarithm of the relative concentration in the j-th interval preceding the measurement. These are called lagged values of C_j.

A_1 = 1 if the worker is sanding with the ventilated sander, otherwise the value is 0.

A_2 = 1 if the worker is not sanding, otherwise the value is 0.

β = regression coefficients.

In this model, the regression coefficient for A_1 is an estimate of the concentration difference between the ventilated and the nonventilated sander. The value of this regression coefficient and the other regression coefficients are shown in Figure D2 under the column labelled "Estimate." The physical magnitude of this estimate is low because of the inclusion of lagged values of C_j. The column labelled "Pr > ¦T¦" is the probability that chance could have caused the observed regression coefficient to differ from zero. The probabilities for the regression coefficients for C_j indicate that autocorrelation is occurring. The probability for A_1's regression coefficient is 0.0003. This indicates that it is unlikely that the observed difference is due to chance, and one can conclude that the ventilated sander does reduce the aerosol concentration.

The real-time data collected during the spray painting operation was used to fit a model of this form:

$$C = \beta_o + \sum_{k=1}^{11} \beta_k C_k + \sum_{j=1}^{4} \beta_{j+11} L_j + \beta_{16} T_s + \beta_{17} T_{NS}$$

Where:

L_1 = 1 if the worker is away from the object being spray painted, otherwise the value is 0.

L_2 = 1 if the worker is behind the object being spray painted, otherwise the value is 0.

L_3 = 1 if the worker is in front of the object being spray painted, otherwise the value is 0.

L_4 = 1 if the worker is on the left hand side of the object being spray painted, otherwise the value is 0.

T_S = Cumulative time spent spraying since last break in spraying (seconds).

T_{NS} = Cumulative time spent with spray gun off since the last episode of spraying.

General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1053.445321	95.767756	2684.10	0.0
Error	959	34.216744	0.035680		
Corrected Total	970	1087.662065			

R-Square	C.V.	Root MSE	LOGC Mean
0.968541	-6.720999	0.188890	-2.8104522

Dependent Variable: C

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		-0.040594737 B	-2.27	0.0233	0.01786977
C1		1.040180383	32.22	0.0001	0.03228142
C2		-0.080487968	-1.73	0.0843	0.04658461
C3		-0.045055881	-0.97	0.3344	0.04664895
C4		0.025904838	0.56	0.5781	0.04656780
C5		-0.041088151	-0.88	0.3770	0.04648488
C6		0.046441989	1.00	0.3182	0.04650026
C7		-0.024902833	-0.54	0.5924	0.04650167
C8		0.014503289	0.31	0.7547	0.04640520
C9		0.022963210	0.71	0.4752	0.03214755
ACTIVITY	1 (A_1)	-0.096387608 B	-3.62	0.0003	0.02662823
	2 (A_2)	-0.074639294 B	-2.62	0.0089	0.02846210
	3	0.000000000 B	.	.	.

Figure D2. Selected output from SAS for the analysis of the real-time data collected when the ventilated sander was in use. The terms C1-C9 is the value of C in the preceding 1 through 9 time intervals respectively.

The terms T_S and T_{NS} were included because concentration increases when spraying occurs and decreases when spraying ceases. As a source of variability, an analysis of variance, conducted as part of the SAS General Linear Models procedure, showed that the worker's location did not significantly affect worker exposure (probability of a larger F = 0.2373).

General Linear Models Procedure

Dependent Variable: C

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	155.1365311	9.1256783	653.51	0.0
Error	478	6.6748442	0.0139641		
Corrected Total	495	161.8113754			

R-Square	C.V.	Root MSE	LV Mean
0.958749	-15.35271	0.118170	-.76969999

General Linear Models Procedure

Dependent Variable: C

Parameter		Estimate		T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		-0.023031664	B	-1.01	0.3123	0.02277085
C1		1.286321990		28.32	0.0001	0.04542764
C2		-0.373120006		-5.03	0.0001	0.07414134
C3		-0.140338485		-1.85	0.0650	0.07587944
C4		0.097012175		1.28	0.2017	0.07587399
C5		0.021303748		0.28	0.7797	0.07612342
C6		0.048775851		0.64	0.5214	0.07600726
C7		0.027800068		0.37	0.7152	0.07613752
C8		-0.137610616		-1.81	0.0708	0.07599124
C9		0.116037701		1.53	0.1273	0.07595812
C10		0.087445420		1.18	0.2397	0.07429013
C11		-0.081027847		-1.78	0.0761	0.04557663
LOC	away (L_1)	0.011965781	B	0.49	0.6245	0.02442893
	behind (L_2)	-0.015378830	B	-0.65	0.5171	0.02372164
	front (L_3)	-0.015400296	B	-0.69	0.4895	0.02226424
	left (L_4)	-0.039941736	B	-1.45	0.1469	0.02749389
	right	0.000000000	B	.	.	.
TNS (time not sanding)		-0.000440506		-2.53	0.0118	0.00017433
TS (time sanding)		0.001122704		2.41	0.0164	0.00046633

Figure D3. Selected SAS output from the analysis of real-time data collected during spray painting with an HVLP spray painting gun.