SURVEY REPORT

CONTROL TECHNOLOGY FOR AUTOBODY REPAIR AND PAINTING SHOPS

AT

Church Brother's Collision Repair
Greenwood, Indiana

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DISCLAIMER

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SUMMARY

A metal-inert gas welder with built-in ventilation was evaluated at an autobody repair shop Real-time monitoring data suggested that this welder provided a 7 to 30 fold reduction in worker fume exposure over an unventilated welder The results of conventional air sampling conducted with pumps and filters indicated a smaller reduction due to cross contamination from an adjacent welding operation Because of the limited nature of this evaluation, further evaluation of this type of control technology is needed

Keywords SIC 7531, total particulate, iron, zinc, calcium, welding fumes, ventilation, high velocity-low volume ventilation, video exposure monitoring, real-time monitoring, aerosol photometers

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 (DHHS), 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 hazard 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

This study of autobody repair is being undertaken by ECTB 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 state consultation programs From these letters, contacts with state consultation program representatives, discussion with the Division of Surveillance Hazard Evaluations and Field Studies (DSHEFS) and the Division of Respirators Disease Studies (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 candidates small businesses, autobody repair and painting shops were one of several potential workplaces that were selected for study

The objective of this study of autobody repair and painting shops is to provide these shops with information about practical, commercially-available control methods that control 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 field evaluations will be compiled with the available literature 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

As part of this overall study, techniques for controlling air contaminants generated during welding operations are being studied Techniques for controlling welding fumes have applications in many other industries At this body shop, a metal inert gas (MIG) welder with built-in ventilation was evaluated This welder has a built-in high velocity, low volume (HVLV) hood which uses a small volume of air to capture welding fume at the source

Shop Description and Process Description

This autobody shop employs 14 workers, 10 repairing cars and 4 painting cars The shop was opened in February of 1991 and repairs 30-35 cars per week It is located in a new building and the equipment in this shop was selected to minimize worker exposure to air contaminants during autobody repair Cars are sanded with ventilated sanders and some cars are painted with primers at ventilated vehicle preparation stations (CNW, Holland) At these vehicle preparation stations, air is exhausted through an exhaust grate which is perpendicular to the floor and some of this air is recirculated through filters which are located above the car being repaired Spray painting is done in one of three booths One booth is designed for spray painting individual automotive parts such as fenders The other two booths are down-draft spray painting booths that have provisions for curing the paint at elevated temperatures

When the vehicles are being repaired, MIG welders are used to attach some replacement parts to the car The subject of this study, a Hansen MIG ARM Articulated Overhead Workstation™ (model CH7290, U S Patent 5,025,126, Henning Hansen Inc , Pickering, Ontario, Canada), was installed on a trial basis prior to purchase The cost of this unit was $1600 at the time of the survey

Description of Ventilated MIG Welder

The HANSEN MIG ARM and ventilated welder are shown in Figures 1 and 2 To use the welder, the arm is positioned near where the welding is done The negative pole on the power supply is attached to the car The positive pole is wire that is fed from the welding gun When the trigger on the welding gun is depressed, metal wire is fed from a spool on the ARM, through the ARM and gun, and to the pieces being welded together An electrical current flows through the wire and across the gap between the wire and the objects being welded together The arc, which occurs because of this gap, melts the metal wire and fuses the two pieces together [1] The weld is protected from oxidation by argon gas that has a flow rate of 40 cubic feet per hour In Figure 3, note that the worker is very close to the parts being welded together and that the worker used a hand-held welding shield to protect his eyes from the arc At the point of generation, welding fumes are exhausted through the slots on the gun shown in Figure 2 The air is exhausted by a welding fume extractor (HH0750, Henning Hansen, Pickering Ontario), passed through filters (HH5712, Henning Hansen, Pickering, Ontario), and discharged back into the workplace

At this work site, the air from the welder is cleaned before it is recirculated back into the workplace Because filters can have holes, there is a possibility of inadvertently recirculating contaminated air into the workplace As a result, ACGIH's criteria for the recirculation of air from

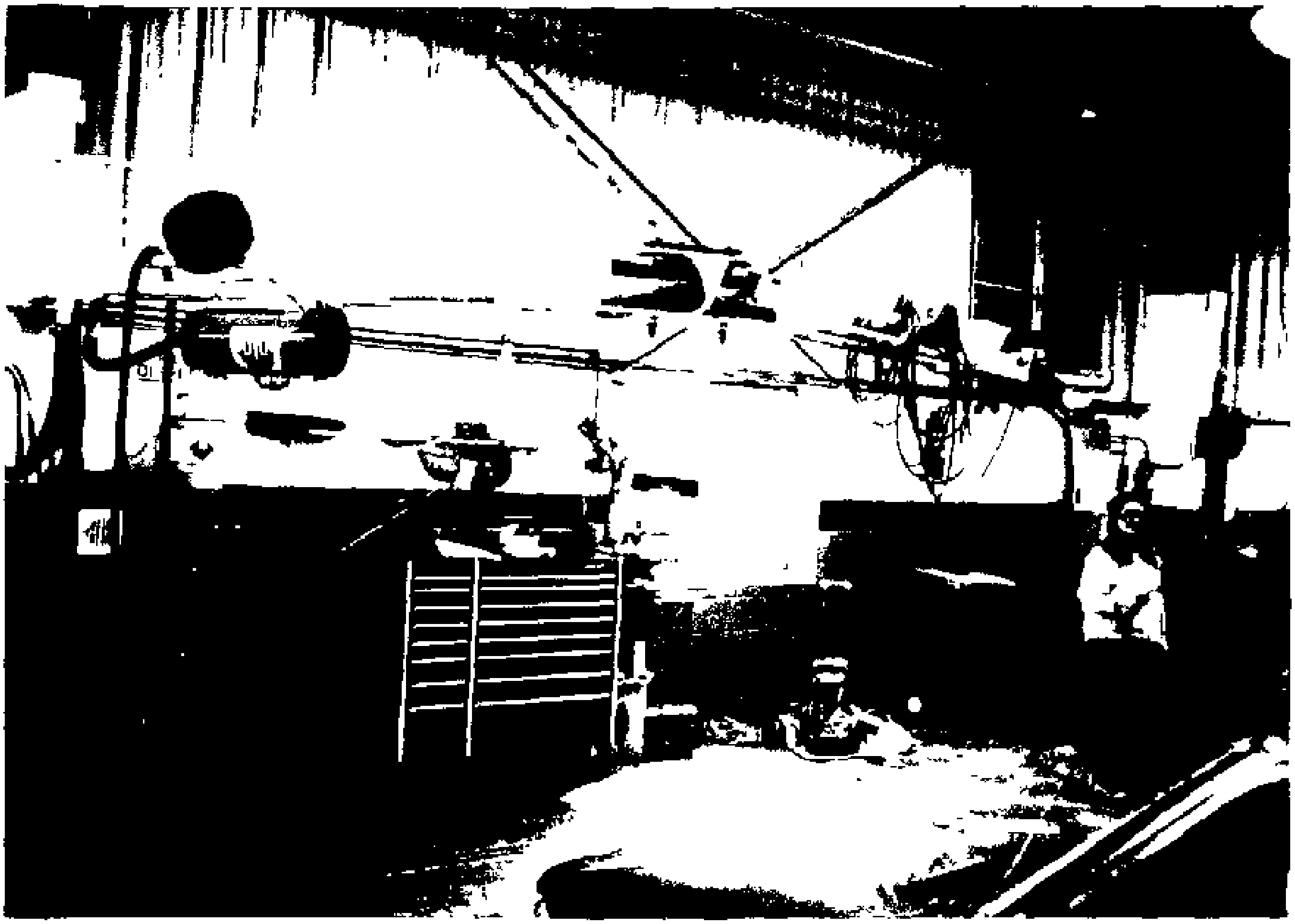

Figure 1   Picture of HANSEN MIG ARM set up for MIG welding

Figure 2 Photograph of MIG welder with smoke extraction

Figure 3 Picture of technician welding on an autobody Notice that the worker is very close to the object being welded

industrial exhaust systems should be used[2] In using this criteria, one must consider the probability and consequences of an air cleaner failure In addition, a monitoring system must be used which provides adequate warning of an air cleaner failure Because the safe recirculation of air involves extra complications and expense, one needs to compare this extra expense to the value of the heat saved by recirculation Because this welding system involves a very low air flow, the air from the air cleaner should simply be ducted outside

POTENTIAL HAZARDS OF WELDING IN AUTOBODY SHOPS

During MIG welding, the heated metal wire and objects can generate metal fumes Welding fumes consist of oxides of the metal being welded and particulate contaminants from the welding rod Workers, who are welding, can develop metal fume fever from exposure to freshly generated welding fumes[3] Symptoms last for 24 hours and include chills, trembling, nausea and vomiting During this 24 hour period there is a reduction in lung function but no evidence of radiological changes in the lung Because of these concerns, the ACGIH recommends that worker exposure to welding fumes be limited to 5 mg/m[3-4] In reviewing the health effects of welding, NIOSH summarized the available literature on the adverse health affects associated with welding[5]

> "Analysis of data obtained from welders reveals several types of adverse effects associated with various welding processes The respiratory system is the primary target of injury Metal fume fever and pneumonitis are the most common acute respiratory diseases associated with welding as a result of short-term exposures to high concentrations of fumes and gases Chronic respiratory diseases such as cancer, pneumoconiosis, and bronchitis have been observed among welders exposed to welding fumes and gases (and possibly to asbestos in some instances over long periods) In addition to respiratory diseases, cancers of the kidney and other urinary tract organs, and the subglottic area of the larynx have been described in such workers Other health effects and injuries reported include cardiovascular and gastrointestinal diseases, skin sensitization, hearing loss, and eye and musculoskeletal injury Some evidence indicates a possible relationship between adverse reproductive outcomes and exposure to welding fumes Because of the diversity of welding techniques, processes, and materials used, most of these studies lack sufficient information to associate a specific chemical or physical agent with a particular health effect "

Besides causing metal fume fever, one also must be concerned about the health effects of individual welding fume constituents In addition, painted surfaces can burn and release decomposition products into the workers' breathing zone Furthermore, material safety data sheets for some automotive paints report that toxic metals such as chromium and lead are present in some formulations Welding can generate ozone and nitrogen oxides[6] High concentrations of ozone can be emitted when MIG welding is done on aluminum The following discussion briefly summarizes some health effects attributed to specific metal fumes and gases that may be generated during welding

Iron oxide

Welding on iron surfaces produces an iron oxide fume Excessive exposure to this fume can cause the development of lung changes that show up on X-rays

However, these lung changes do not appear to be associated with any physical impairment of the lung [7]

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 Certain insoluble hexavalent chromium compounds are suspect carcinogens [8]

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 [9] 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 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 [10-11] Lead exposure is associated with fetal damage in pregnant women [9 11] Lastly, elevated blood pressure has been positively related to blood lead levels [12-13]

Ozone

Ozone is irritating to the eyes and upper respiratory tract At concentrations between 0 2 and 2 0 ppm, symptoms of chronic exposure include headache, weakness, shortness of breath, drowsiness, reduced ability to concentrate, slowing of heart and respiration rate, and visual changes [14] Concentrations in excess of 2 ppm for a few hours can cause pulmonary edema, congestion and hemorrhage [4]

Oxides of Nitrogen

Oxides of nitrogen include nitrogen dioxide and nitric oxide Concentrations of 1 5 to 5 ppm may cause narrowing of the peripheral and central airways and reduced diffusing capacity of the lung These changes may be responsible for a fall in the maximum amount of oxygen which can be dissolved in the blood At these concentrations, symptoms include respiratory irritation and coughing Higher exposures may cause shortness of breath, chest pain, and lung edema [15]

Zinc oxide

The metal surfaces of some cars are galvanized with zinc Welding on these surface causes the formation of a zinc oxide fume Excessive exposure to zinc oxide fume can result in metal fume fever The symptoms of metal fume fever include fever, chills, muscular pain, nausea and vomiting Workers may develop metal fume fever at zinc oxide concentrations greater than 5 mg/m [3-4]

Electromagnetic Radiation

Welding involves potential eye injury due to splattering and exposure to nonionizing radiation in the ultraviolet (UV) and infrared wavelengths (IR) [5] Although these hazards are beyond the scope of this study, they need to be discussed UV radiation from welding may cause acute keratoconjunctivitis, also known as arc eye or welder's flash This disorder causes blurred vision, lacrimation, burning pain and headache These symptoms appear 4 to 12 hours after exposure has begun and may last for 2 days Visible radiation can cause damage to the eyes retina IR radiation can cause thermal damage to the cornea of the eye and has been associated with the formation of lenticular cataracts

EXPOSURE EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures such as welding operations, NIOSH field staff employ environmental evaluation criteria for assessment of several 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 It is, however, important to note that not all workers will be protected from adverse health effects even 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 criteria 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 can be used for the workplace are 1) NIOSH Recommended Exposure Limits (REL's), 2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLV's), and 3) the U S Department of Labor (OSHA) Permissible Exposure Limits (PEL's) The OSHA PEL's are required to consider the feasibility of controlling exposures in various industries where the agents are used, the NIOSH REL's, 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 an OSHA PEL's

A Time-Weighted Average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8 to 10 hour workday Some substances have recommended short-term exposure limits (STEL) or ceiling values that are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures

Table 1 summarizes exposure limits for air contaminants which may be generated during welding operations in autobody shops In reviewing this table, note that NIOSH recommends exposure limits for specific components of the welding fume However, OSHA does have an exposure limit for the total mass of welding fume in the air

TABLE I
Exposure Limits for Some Fumes and Gases Which May Be Generated During Welding in Autobody Shops

Substance	NIOSH Recommended Exposure Limit[16]	OSHA Permissible Exposure Limit[17]		ACGIH Threshold Limit Value (TLV)[18]	
	TWA[a]	TWA[b]	STEL[c]	TWA[b]	STEL[c]
Calcium oxide	2 mg/m^3	5 mg/m^3		2 mg/m^3	
Iron oxide fume	5 mg/m^3	10 mg/m^3		5 mg/m^3	
Lead	Less than 0 1 mg/ m^3 Air level to be maintained so that worker blood level remains below 0 06 mg/100g of whole blood	50 $\mu g/m^3$		0 15 mg/m^3 of air The biological exposure index is 50 µg/ 100 mL of blood	
Nitrogen dioxide	1 ppm as an STEL		1 ppm	3 ppm	5 ppm
Nitric oxide	25 ppm	25 ppm		25 ppm	
Ozone	0 1 ppm as a ceiling	0 1 ppm	0 3 ppm	0 1 ppm as a ceiling	
Particulate (not otherwise regulated) total respirable		15 mg/m^3 5 mg/m^3		10 mg/m^3 5 mg/m^3	
Zinc Oxide fume	5 mg/m^3 as a TWA 10 mg^3 as a STEL	5 mg/m^3		5 mg/m^3	10 mg/m^3
Welding Fume	Existing RELs for specific substances are applicable	5 mg/m^3		5 mg/m^3	

[a] TWA - 10-hour Time Weighted Average for a 40 hour week
[b] TWA - 8-hour Time Weighted Average
[c] STEL - Short-Term Exposure Limit

EVALUATION PROCEDURES

The evaluation's objective was to document the ability of the ventilated MIG welder to control worker exposure to welding fumes During a one-hour repair job, air contaminant exposures were measured while using the ventilated MIG welder and again while using a conventional MIG welder A second nearby worker, who was using unventilated grinders and MIG welders, also was sampled for a four-hour period

Comparison of Ventilated and Unventilated MIG Welder

These welders were compared while a worker repaired a car with extensive damage to its front end To facilitate the repairs, the car's engine was removed For a half-hour period, the worker used an unventilated MIG welding gun which did not control worker exposure to welding fumes During a second half-hour period, the ventilated MIG welder was used During both periods, the metal fume concentrations were measured in the workers breathing zone and at the base of the MIG welding arm and the worker's activities were videotaped A Hand-held Aerosol Monitor (HAM) manufactured by PPM Inc , Knoxville, Tennessee was used to measure the fume concentration This instrument is a light-scattering device and its response is dependent upon the particles' optical characteristics The HAM responds to respirable particles but does not differentiate between the different metal fumes For these reasons, results are reported as relative concentrations (rather than absolute levels) The HAM was used with the following settings time constant - 1 second, range - 0-2 mg/m^3 The analog output of the HAM was recorded on a data logger (Rustrak Ranger, Gulton, Inc , East Greenwich, Rhode Island) When the data collection was completed, the data logger was downloaded to a portable computer (Compaq Portable III, Compaq Computer Corporation, Houston, Texas) for analysis

A calibration manifold was mounted on the HAMs and it held a filter holder that contained a 37 mm mixed cellulose ester membrane filter (type AA, Millipore Inc, Bedford MA) Tubing connected the outlet of the filter to a critical flow orifice and a vacuum pump which caused a flow of 13 lpm through the HAMs' sensing volume and through the membrane filter described above The pump maintained a vacuum greater than 15 inches of Hg down stream of the critical flow orifice The filter was analyzed using NIOSH method 7300 for the metals listed in Table II [19]

TABLE II Analytes and Limits of Detection	
Analyte	Limit of Detection µg/filter
Aluminum	5
Calcium	5
Cadmium	1
Chromium	1
Iron	1
Lead	2
Titanium	1
Zinc	1

Exposure Measurements on Worker Repairing Cars

The total particle exposure and metal exposures of a second worker were measured This worker did some repair work using an unventilated grinder and unventilated MIG welder during the repair of a car body He also was involved in some vehicle preparation work NIOSH method 0500 was used to measure his total particle exposure [19] In this method, a known volume of air is drawn through a preweighed PVC filter at a flow rate of 5 0 liters per minute The weight gain of the filter is used to compute the milligrams of particles per cubic meter of air A second sample was collected for metals on a millipore AA filter at a flow rate of 2 0 liters per minute NIOSH method 7300 was used to analyze these air samples for the elements shown in Table II [19] Area samples for metals and total particulate were collected at a window sill near the workers' tool boxes

Ventilation Measurements

The exhaust flow rate from the MIG welder was measured by placing the welding gun in the box illustrated in Figure 4 This box was used so that the exhaust volume could be accurately calculated from a knowledge of the duct's area and the velocity in the duct The mechanism for the feeding the wire into the welder gun was deactivated The welder was turned on and the air velocity in the exhaust duct was measured using a hot wire anemometer (model 1040 Digital Air Velocity Meter, Kurz, Carmel Valley California) The air velocity was measured by inserting the hot wire anemometer's probe through the probe port into the center of duct shown in Figure 4

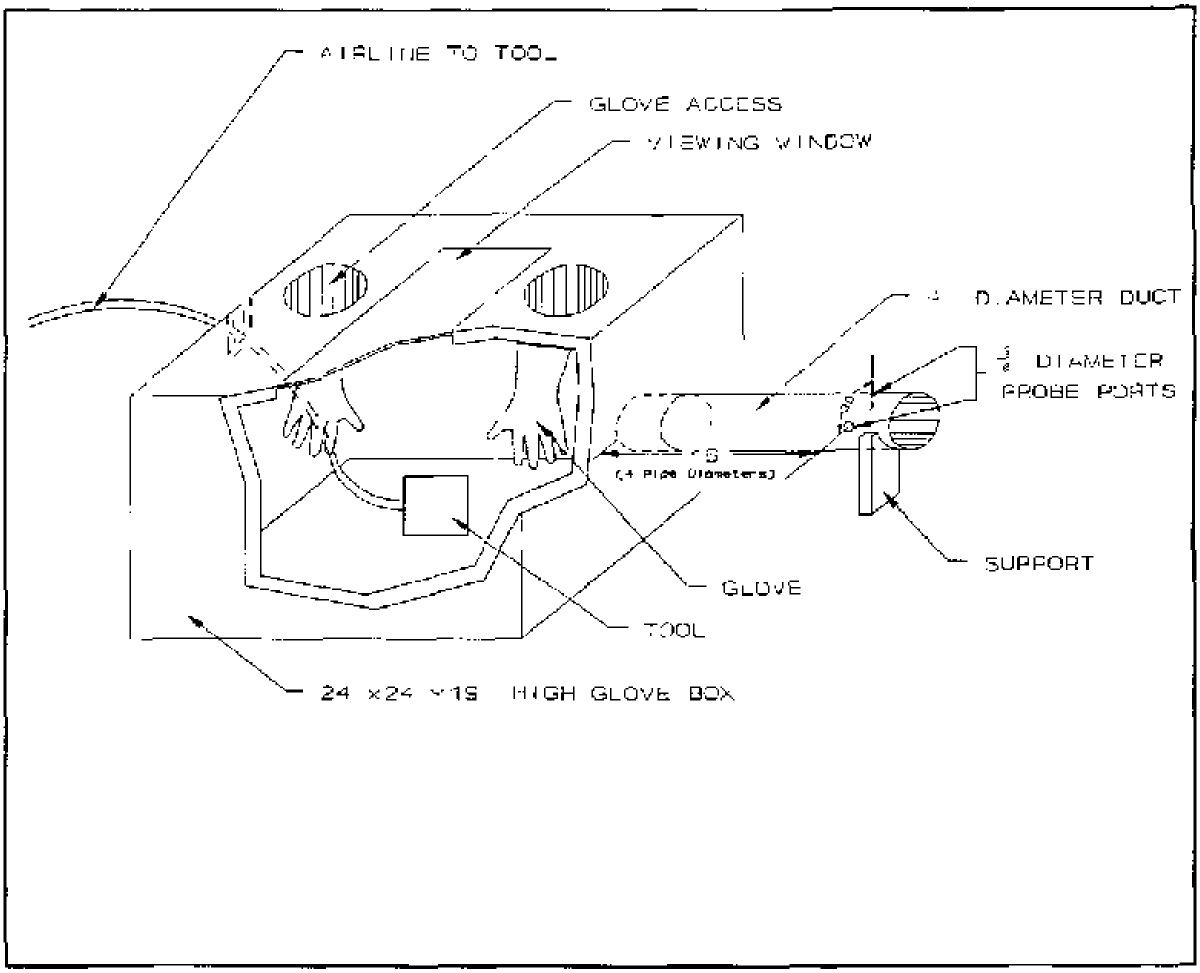

Figure 4   Schematic illustrating box used for measuring air flow into MIG welder

Detector Tube Measurements

During MIG welding, exposures to oxides of nitrogen and ozone were evaluated by using detector tubes for ozone (ozone 0,051b part 67331181, Draeger, Lubeck, Germany) and oxides of nitrogen (nitrose gas 0 5a, part CH29401, Draeger, Lubeck, Germany)

RESULTS

The air flow into the ventilated MIG welder was measured to be 30 cubic feet per minute Detector tube measurement indicated that the oxides of nitrogen concentration was less than 0 1 ppm and the ozone concentration was less than 0 01 ppm The results of individual filter samples are tabulated in Appendix A Iron, zinc, and calcium were detected on the filters analyzed for metals, the other metals listed in Table 2 were not detected None of the concentrations that are listed in Appendix A exceeded the exposure limits listed in Table 1

Figure 5 shows that the type of welder affected the total metal concentrations measured in the worker's breathing zone and near the base of the MIG welding arm (The total metal concentration is the sum of the concentrations of iron, zinc, and calcium, it is used as an index of control and a measure of the total amount of welding fume in the air) When the ventilated MIG welder is used, the total concentration of metals on the personal sample was a factor of three lower than when the conventional welder was used However, the total metal concentration near the base of the MIG welder increased when the ventilated MIG welder was used While data were being taken with the ventilated MIG welder, other unventilated welders were used and this may have caused the increased area sampling results while the ventilated MIG welder was in use Thus, these results probably understate the difference between the two welding tools

The relative concentration measured by the HAM mounted on the worker was a function of the type of welder and the location at which the welding was done, either inside or outside the car's passenger compartment Figure 6 graphically contrasts the relative concentration with the type of welder and sampling location When welding occurred inside the car, the ventilated MIG welder appeared to cause a 30 fold reduction in exposure Outside the car, the reduction in exposure was a factor of 3 5 For the measurements taken with the ventilated MIG welder, the location at which the welding occurred did not affect the relative concentration measured by the HAM Appendix B summarizes the findings of a statistical analysis of the real-time data

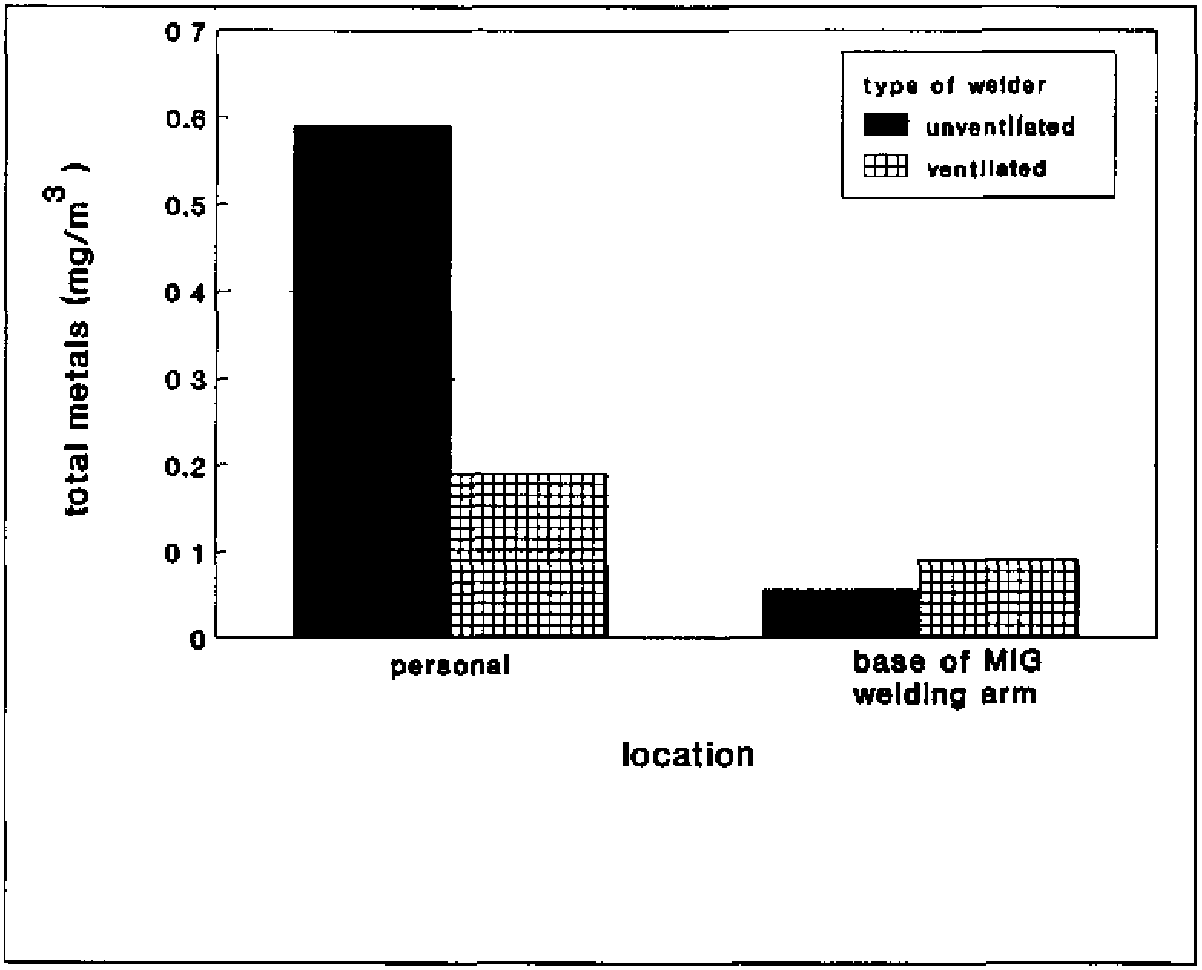

Figure 5 The use of a ventilated MIG welder reduces the workers exposure to metal aerosols inspite of a concentration increase at the area sampling location

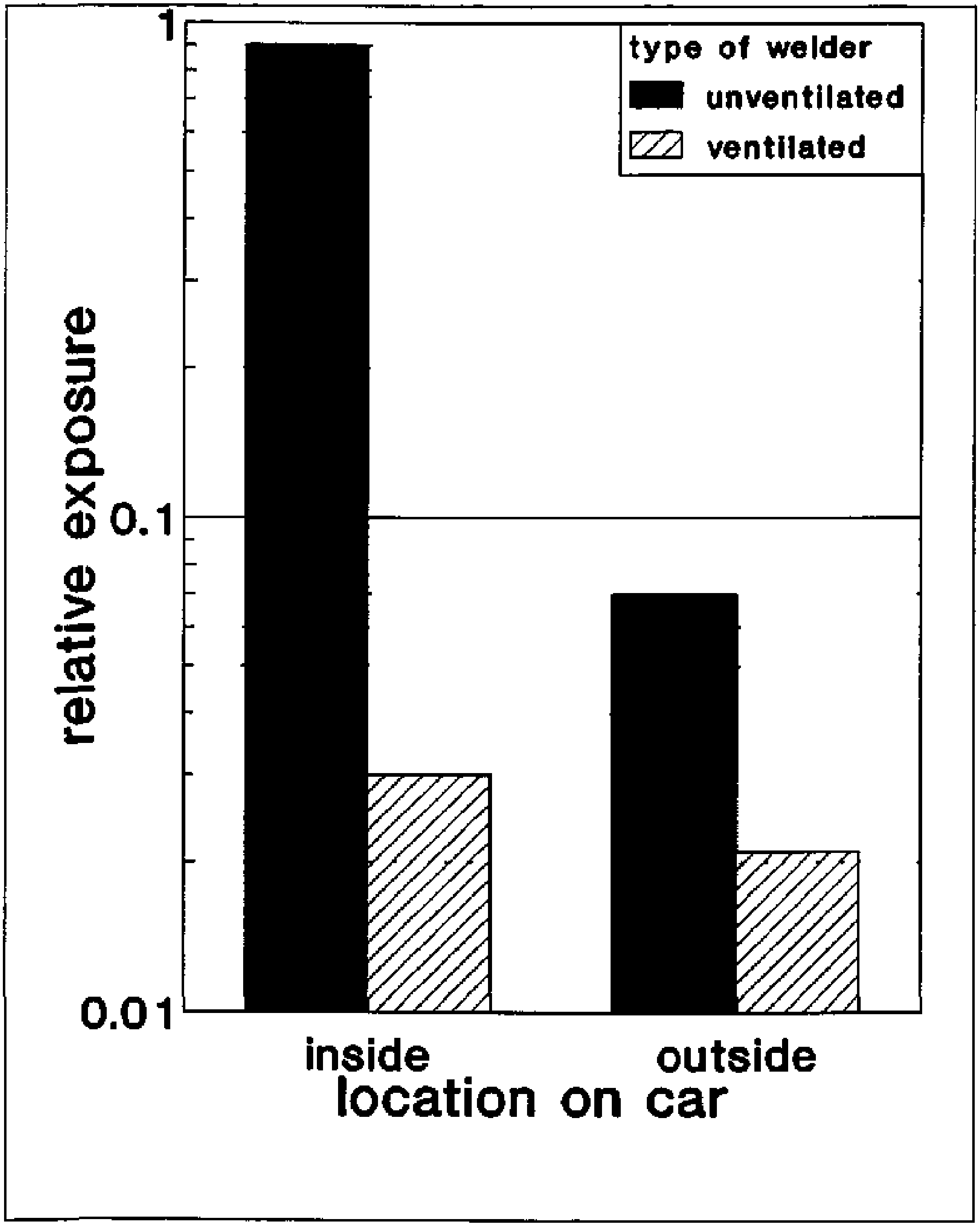

Figure 6   Relative exposure as a function of welder type and location on the car

DISCUSSION

The results summarized in Figures 5 and 6 indicate that ventilation of the MIG welder does reduce worker exposure to welding fumes Any conclusions drawn from this study need to be tempered by the fact that sampling was done on a single repair job As a result, it can not be determined whether the concentration differences presented in Figure 5 are real or simply reflect statistical fluctuations in the measured concentrations However, because the local exhaust ventilation is located very close to the emission source, it is reasonable that such ventilation would provide very good control of fumes generated on the top surface of the object being welded

Some welding fumes were observed to not be captured by the ventilated welder This suggests that the ventilated MIG welder provided incomplete control of the fumes generated during welding Occasionally, the worker moved the welder before the metal had cooled sufficiently to stop generating fumes In other situations, the metal on the other side of the welding area became sufficiently hot to generate fumes Apparently, the car body obstructs the capture of these fumes by the ventilated welder

As shown in Figure 6 and in Appendix B, welding inside the car with the unventilated welder increased the relative concentration measurements as compared to similar welding done outside of the car's body This increase is probably due to the decreased dilution of the welding fumes inside the car

CONCLUSIONS

The ventilated MIG welder appeared to provide a very noticeable reduction in the welding fume exposure of an autobody repair technician Although the available data indicates that ventilated MIG welders are probably useful, this evaluation provides little insight into the capabilities and limitations of this approach to controlling worker exposure to welding fumes To obtain better information, further field and laboratory studies could be conducted

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APPENDIX A - Listing of Air Sampling Results
Appendix A
Air Contaminant Concentrations

description	type of sample	time			concentration (mg/m^3)				
		start	stop	flow rate (lpm)	iron	zinc	calcium	total metals	total particles
Samples taken while worker was using an unventilated MIG welder to repair an extensively damaged car The area samples were collected near the base of the MIG welding arm	p	9 00	9 30	13 8	0 31	0 27	0 02	0 60	
	a	9 00	9 30	13 1	0 03	0 03	nd	0 06	
Samples taken while worker was using ventilated MIG welder to repair an extensively damaged car The area sample was collected near the base of the MIG welding arm While these samples were collected, additional welding was done at a nearby workstations with no provisions for controlling the welding fumes	p	9 45	10 45	13 8	0 08	0 11	0 01	0 19	
	a	9 45	10 45	13 1	0 03	0 06	nd	0 09	
Samples collected on autobody repair technician who was doing a variety of tasks throughout the body shop He performed some welding with an unventilated MIG welder The area samples were collected on a window sill near the conventional welding guns	p	7 47	11 05	2	0 03	0 01	0 02	0 06	
	a	7 45	11 10	2	0 04	0 04	0 01	0 09	
	p	7 47	11 05	5					0 90
	a	7 45	11 10	5					0 21

Abbreviations

p personal air sample
a area samples
mg/m^3 milligrams per cubic meter
nd not detected

APPENDIX B - Statistical Analysis of Real-Time Data

The readings from the HAM were imported into a spreadsheet The interval between readings was one second For each reading, the videotape of the worker's activity was viewed and entries where made in separate columns of a spreadsheet to describe activities Three explanatory variables were used to describe the worker's activity during the welding operations

1 LOCATION This variable describes whether the worker is welding the outside of the car or inside the passenger compartment In the passenger compartment, the welding took place either on the front floor or upon the structures which support the dash board

2 ACTIVITY This variable describes whether the MIG welder was in use

3 WELDER This variable describes whether the ventilated or unventilated MIG welder was in used

The SAS General Linear Models Procedure (SAS, Cary, North Carolina) was used to evaluate whether the HAM readings on the worker were a function of the three explanatory variables listed above Data analysis was performed on the natural logarithms of the HAM readings (termed "LCP" in Figure B1) The variable LCP was modelled as a function of the three explanatory variables described above, the interactions between these variables, and the measurements in the seven previous readings (LCP1-LCP7) The latter variables were included in the model to address the fact that sequential measurements usually involve serial correlation

The results of the statistical analysis are presented in item 1 of Figure B1 In this figure, the "Pr > F" (the probability of a larger F statistic) is the probability that chance could have caused such a large difference in the observed readings If the probabilities are less than 0 05, one concludes that the observed differences are not due to chance and that the variable in question is affecting the HAM reading This analysis showed that the variables WELDER, LOCATION and the interaction between these two variables (WELDER*LOC) had a significant affect upon the HAM readings The interaction term indicates that the difference in HAM readings between the two welders varies with the location at which the welding is done

Because the HAM's response varies with both Location and Welder, t-tests were done to examine the differences in exposure between the different combinations of Location and Welder This test was conducted by using the Least-Squares Means option in the SAS General Linear Models procedure [20] The results of this test are shown as item 2 in Figure B1 This table evaluates difference in HAM readings between all possible combinations of WELDER and LOCATION Each combination of WELDER AND LOCATION (abbreviated LOC) is given a number under the column labelled "i/j" For each difference between the combinations, a t-statistic and "Pr > |T|" (probability of a larger t-statistic) is given For example, the difference between a conventional welder used inside the car (number 1 in the column labelled "i/j") and a ventilated welder used inside the car (number 3 in the column labelled "i/j") is evaluated by examining the first two entries under the column labelled "3"

The first number is the t-statistic (T) for the difference The second number is the probability that a larger value of T could be obtained by chance This probability is the probability that chance could have caused the observed difference in HAM readings When this probability is less than 0 05, one concludes that observed difference is too large to be due to chance When the ventilated MIG welder was used, the relative concentration did not change with location of the welding When the conventional MIG welder was used, the relative concentration did vary with the location of the welding

General Linear Models Procedure

Dependent Variable LCP

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	1455 227700	103.944836	8815 22	0.0
Error	2763	32.579953	0 011792		
Corrected Total	2777	1487 807653			

R-Square	C.V	Root MSE	LCP Mean
0.978102	-5.608072	0 108589	-1 9362935

ITEM 1

Dependent Variable LCP

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LCP1	1	51 42368393	51 42368393	4361.08	0 0
LCP2	1	1.50756089	1 50756089	127 85	0.0001
LCP3	1	0 00234079	0 00234079	0 20	0.6560
LCP4	1	0 01993304	0 01993304	1 69	0.1936
LCP5	1	0 01337522	0 01337522	1 13	0.2870
LCP6	1	0.00454392	0 00454392	0 39	0.5348
LCP7	1	0.01198031	0 01198031	1 02	0.3136
ACT1 (ACTIVITY)	1	0.00032523	0 00032523	0 03	0.8681
LOC (LOCATION)	1	0.30382186	0 30382186	25 77	0.0001
WELDER	1	0.63582737	0 63582737	53 92	0.0001
ACT1*LOC	1	0.00473161	0 00473161	0.40	0.5265
ACT1*WELDER	1	0.02010635	0 02010635	1 71	0.1917
WELDER*LOC	1	0.25057493	0 25057493	21 25	0.0001
ACT1*WELDER*LOC	1	0 00167303	0.00167303	0.14	0.7064

ITEM 2

Least Squares Means

WELDER	LOC	LCP LSMEAN	i/j	T for H0: LSMEAN(i)=LSMEAN(j) / Pr > |T| 1	2	3	4
CONVENTIONAL	INSIDE	-1.84600344	1	.	6.457878 0.0001	7 26513 0 0001	8.549009 0 0001
CONVENTIONAL	OUTSIDE	-1.91794440	2	-6.45788 0 0001	.	3.151461 0.0016	4.613212 0.0001
VENTILATED	INSIDE	-1.95311475	3	-7 26513 0.0001	-3 15146 0 0016	.	0.261344 0 7938
VENTILATED	OUTSIDE	-1.95536429	4	-8 54901 0 0001	-4 61321 0.0001	-0 26134 0.7938	.

Figure B1 Selected SAS output