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RESEARCH REPORT

ASSESSMENT of SELECTED CONTROL TECHNOLOGY TECHNIQUES for WELDING FUMES

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

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ABSTRACT

This report presents results of a National Institute for Occupational Safety and Health (NIOSH) welding fume study undertaken to verify findings for a Battelle Institute laboratory ventilation research study when applied under industrial welding plant conditions.

The NIOSH welding fume investigation was conducted at the General Tool Company, Reading, Ohio (a large modern job-shop operation). It verified Battelle's results on effect of air flow direction (in relation to the welder) on fume concentrations in the welder's breathing zone that 1) cross draft air flow (<100 cfm at 90° to the welder) significantly lowers breathing zone fume concentration from that prevailing when no directional air flow is employed and 2) with directional air flow from directly behind the welder (<100 fpm), breathing zone fume concentration levels are approximately equal to that prevailing when no directional air flow is employed.

Other findings included 1) a "smoke exhaust" welding gun in semi-continuous wire fed metal inert gas (MIG) welding can reduce fume concentrations in the welder's breathing zone by at least 70% during mild steel welding and 2) directional air flow from local fans is a risky means of ventilation and should be considered only in the case of a welder welding in an essentially fixed position with cross draft air flow (<100 fpm at 90° to the welder).

A summary table of the latest (1977) existing and recommended threshold limit values and major health effects for welding fumes and gases (including carcinogenic components) is presented. Conclusions and recommendations for conducting industrial plant welding operations to meet the most severe of the NIOSH recommended values (carcinogenic components) are included.

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INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) has been cooperating with the American Welding Society (AWS) sponsored (Battelle Institute conducted) research program "Improving the Welding Environment." The program is providing information pertinent to updating American Standards Institute (ANSI) guidelines on safety and health aspects of welding and cutting (ANSI Standard Z49.1).

Welding involves melting of a metal by either a flame or electric arc in the presence of a flux or shielding gas. It produces particulate fumes and gases from the base metal, the welding rod, the flux, surface coatings or surface contaminants, or a combination of these sources. Welding, arc welding, resistance welding, brazing, solid state welding, and other processes, can be subdivided into 34 different processes in commercial use. Each process has specific applications according to the metals to be joined, the types of product being made, the production facilities available, and the site location of the work. The following are the most widely used processes. Most require some form of worker protection to ensure that exposure to air contaminant concentrations does not exceed the maximum safe exposure limits.

- Shielded metal arc welding
- Metal inert gas (MIG) welding
- Flux cored arc welding
- Tungsten inert gas (TIG) welding
- Oxygen cutting and gouging
- Arc cutting and gouging
- Plasma arc welding
- Thermal spraying
- Submerged arc welding (little contaminant evolution)
- Resistence welding

The welder must frequently breathe the gases and fumes produced by the welding operations since welding fumes rise vertically, due to heating of the gases and air in the area of the arc or flame, and the welder's head is usually positioned close to, or in the fume. Fumes and gases flow around his welding hood and some enter his breathing zone. The contaminant concentration inside the hood is influenced by 1) the design of the hood, 2) the welder's position, 3) the fume generation rate, and 4) local ventilation rate and direction. In some cases, nearby workers may also be exposed to harmful air contaminants but not usually to the same extent as the welder.

Control methods used are 1) general dilution ventilation, 2) local ventilation -- either fixed or portable hoods, or "smoke exhaust" welding guns, 3) air supplied helmets, and 4) complete automation -- elimination of the human welder.

Ventilation has been the principal means of control of air contaminants from welding.

An estimate of the degree of exposure can be made by observation of the haze surrounding the welder's hood, but this estimate may be deceptive. Only the larger fume particles are visible, the gases are invisible, and the fumes may range from highly toxic to simple nuisance dust. Breathing zone air contaminant measurements and analysis are required in each operation. Generally, welding in small, confined, unventilated areas provides maximum health hazards; outdoor welding only infrequently produces overexposure to air contaminants.

The variety of industrial welding situations, the types of welding, as well as the types of structures being fabricated make generalizations on specific local ventilation units difficult. An important factor in the use of ventilation as a control of welding fumes and gases is the adverse effect of excessive linear air movement on weld quality. Both accessibility and "integrity" of the weld must be considered in using ventilation controls. These factors are not clearly defined and must be considered in each case.

A comprehensive set of welding ventilation guidelines is presented by AWS (1). These ANSI (ANSI Z49.1-1973) guidelines specify minimum requirements for both dilution and local ventilation, and for control of specific toxic materials. They have been adopted without major changes into federal safety and health regulations (2). Other guidelines are contained in the American Conference of Governmental Industrial Hygienists (ACGIH) "Industrial Ventilation" (3), "Recommended Industrial Ventilation Guidelines" (NIOSH (4), and "Engineering Control of Welding Fumes" (5). The AWS has recognized the need for upgrading the 1973 ANSI Z49.1 guidelines. Battelle Institute is completing an AWS sponsored two-year detailed research program on welding, brazing, and soldering entitled "Improving the Welding Environment."

This report presents results obtained by NIOSH during a recently completed "in-house" welding fume study conducted under industrial welding plant conditions. The study was undertaken to ascertain whether preliminary findings obtained during Battelle Institutes' rigorously controlled laboratory conducted AWS sponsored study could be validated in commercial welding plant operations. The following two subjects were investigated:

1. The effect of dilution air direction (in relationship to the welder) and velocity of air flow on fume concentration in the welder's breathing zone.

2. Effectiveness and operating characteristics of an advanced model "smoke-exhaust" welding gun as a means of local ventilation.

COMPOSITION, SOURCES, AND LIMITS ON WELDING FUMES AND GASES

Air contaminants, fumes and gases, are by-products of the welding operations. Different welding processes provide varying components, amounts, and rates of contaminant evolution. Fumes consist of solid particles condensing in varying sizes after the volatilization of melted substances. They are commonly identified as slag, splatter, dust, and fume, respectively, as the particle size progressively decreases. Dust is the visible particulate matter (particle diameter over 10 μm) which settles quickly. Welding fumes are the finer particles (under 10 μm) which remain in the air for longer periods of time and may not be visible. An excellently written general discussion is presented in the British Welding Institutes' "The Facts About Fumes" (6).

More than 20 air contaminants have been identified as coming from various welding operations. The major welding fume and gas contaminants are listed in Table 1 by both name and chemical formula. Various exposure limits and related health effects are also included in Table 1. More detailed information can be found in standard references, e.g., ACGIH Threshold Limit Values (TLVs) (7) and Industrial Hygiene and Toxicology (8). Table 1 includes the following exposure value recommendations 1) the 1977 ACGIH TLVs, 2) current federal standards -- Occupational Safety and Health Administration (OSHA), and 3) October 1977 NIOSH recommendations for occupational health standards. Three categories of TLVs are included in the ACGIH Booklet (7):

1. Time weighted Average (TWA) - the concentration for a normal 8-hour workday to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

2. Short Term Exposure Limit (STEL) - the maximum concentration to which workers can be exposed for a period of 15 minutes continuously without suffering from noted harmful effects.

3. Ceiling (C) - the concentration that should not be exceeded even instantaneously.

Fume and gas concentrations are expressed respectively as milligrams per cubic meter (mg/m^3) and parts per million (ppm).

The trend toward lower levels of allowable fume exposures is clearly evident, particularly with those chemical elements which NIOSH has recently identified as having carcinogenic effects -- arsenic, beryllium, cadmium, chromium, and nickel. NIOSH recommended TWA limits (Table 1) are 0.025 mg/m^3 for non-carcinogenic but otherwise hazardous chromium (VI), 0.001 mg/m^3 for carcinogenic chromium (VI), and 0.015 mg/m^3 for metallic nickel. Additional for carcinogenic chromium (VI), any 15-minute (STEL) exposure should be under 0.05 mg/m^3. These recommendations are featured in NIOSH Criteria Documents -- Chromium (VI) (9)

Table 1. Welding fumes and gases - maximum exposure levels.

METALLIC COMPOUND	LIMIT BASIS	EXPOSURE LIMITS: TIME WEIGHTED AVERAGE (TWA) (8-hour) (mg/m^3)			SHORT TERM EXPOSURE LIMIT (STEL) (mg/m^3), 15 MINUTE UNLESS NOTED			MAJOR HEALTH EFFECTS
		1977 ACGIH	OSHA STD.	OCT 77 NIOSH PROP. STD.	1977 ACGIH	OSHA STD.	OCT 77 NIOSH PROP. STD.	
PARTICULATE FUMES								
Alundum	Al_2O_3	10	--	--	20	--	--	None, nuisance dust
Arsenic	As	0.5	0.5	--	0.5		0.002	Lung & lymphatic cancer, Respiratory irritant
Beryllium	Be	0.002	0.002	--	0.025	0.005	0.005 (130 mins.)	Lung cancer, pneumonitis
Cadmium Oxide Fume	Cd	0.05	0.1	0.04	0.15	0.3	0.2	Lung and kidney effects, Pulmonary edema
Chromium (VI)	(Carcinogenic Cr	1	1	0.001	--	--	0.05	Lung cancer, skin ulcers,
	(Non-carcinogenic Cr			0.025	--	--	--	Nasal perforation
Cobalt	Co	0.1	0.1	--	--	--	--	Chemical pneumonitis
Copper Fume	Cu	0.2	0.1	--	--	--	--	Irritant, fume fever
Fluoride	F	2.5	2.5	2.5	--	--	--	Kidney and bone effects
Iron Oxide Fume	Fe_2O_3	5	10	--	10	--	--	None, nuisance dust
Lead, Inorganic	Pb	0.15	0.2	< 0.05	0.45	--	--	Systemic poisoning
Manganese	Mn	5	--	--	--	5	--	Nervous system disorders
Magnesium Oxide Fume	MgO	10	15	--	--	--	--	Fume fever
Molybdenum	(Mo-soluble	5	5	--	10	--	--	Respiratory irritant
	(-Insoluble	10	15	--	20	--	--	Respiratory irritant
Nickel Metal	Ni	1	1	0.015	--	--	--	Lung and nasal cancer, skin effects
Tin Oxide	SnO_2	10	--	--	20	--	--	None, nuisance dust
Titanium Dioxide	TiO_2	10	--	--	20	--	--	None, nuisance dust
Vanadium Fume	V	0.05	--	--	--	0.1	0.05	Eye, skin, and lung effects
Zinc Oxide Fume	ZnO	5	5	5	10	--	15.	Fume fever
Welding fumes (Total Particulate)	--	5	--	--	--	--	--	Depends on constitutents
GASES		TWA as ppm			STEL as ppm			
Carbon Monoxide	CO	50	50	35	400	--	200	Asphyxiant
Carbon dioxide	CO_2	5,000	5,000	10,000	15,000	--	30,000 (10 mins.)	Respiratory effects
Hydrogen Fluoride	HF	3	3	2.5 (mgF/m^3)	--	--	5 (mgF/m^3)	Skin, eye irritation, bone effects
Nitrogen Dioxide	NO_2	5	5	--	--	--	1	Airway effects
Nitrogen Monoxide	NO	--	25	25	--	--	--	Blood effects
Ozone	O_3	0.1	0.1	--	0.3	--	--	Pulmonary edema
Phosgene	$COCl_2$	0.1	0.1	0.1	--	--	0.2	Airway effects

and Inorganic Nickel (10). The cited epidemiological data demonstrate that inorganic nickel and some hexavalent chromium compounds can be carcinogenic. However, not all hexavalent chromium compounds are carcinogenic. Insufficient data are available to prove that the nickel and chromium fume compounds given off during stainless steel welding are definitely carcinogenic. The above listed NIOSH recommendations have not to date been promulgated by OSHA for enforcement.

That stainless steel welding fumes are strongly suspected of being carcinogenic is the basic conclusion of recent Danish reports (11 and 12) dated August and December 1977, respectively. Dr. Stern and Associates in the Danish Welding Institute and Royal College of Pharmacy have applied knowledgeable execution of different welding processes (under varying conditions) combined with biological assay techniques to the resultant welding fumes to provide specific conclusions on mutagenic activity of the fumes. Mutagenic activity is strongly related to carcinogenicity in humans. There is an approximate 90 percent chance that a mutagen will be a human carcinogen according to Dr. Stern. Results of application of the Salmonella microsome mutagenicity test of Ames demonstrated:

1. Welding fumes from mineral metal arc welding (coated steel electrodes) of stainless steel are highly mutagenic but those from mild steel are not.

2. Mutagenicity of stainless steel welding fumes is strongly process and process parameter dependent.

3. Stainless steel welding fumes from manual metal arc (MMA) welding are three to four times as heavy and also much more mutagenic than those from MIG and TIG welding processes.

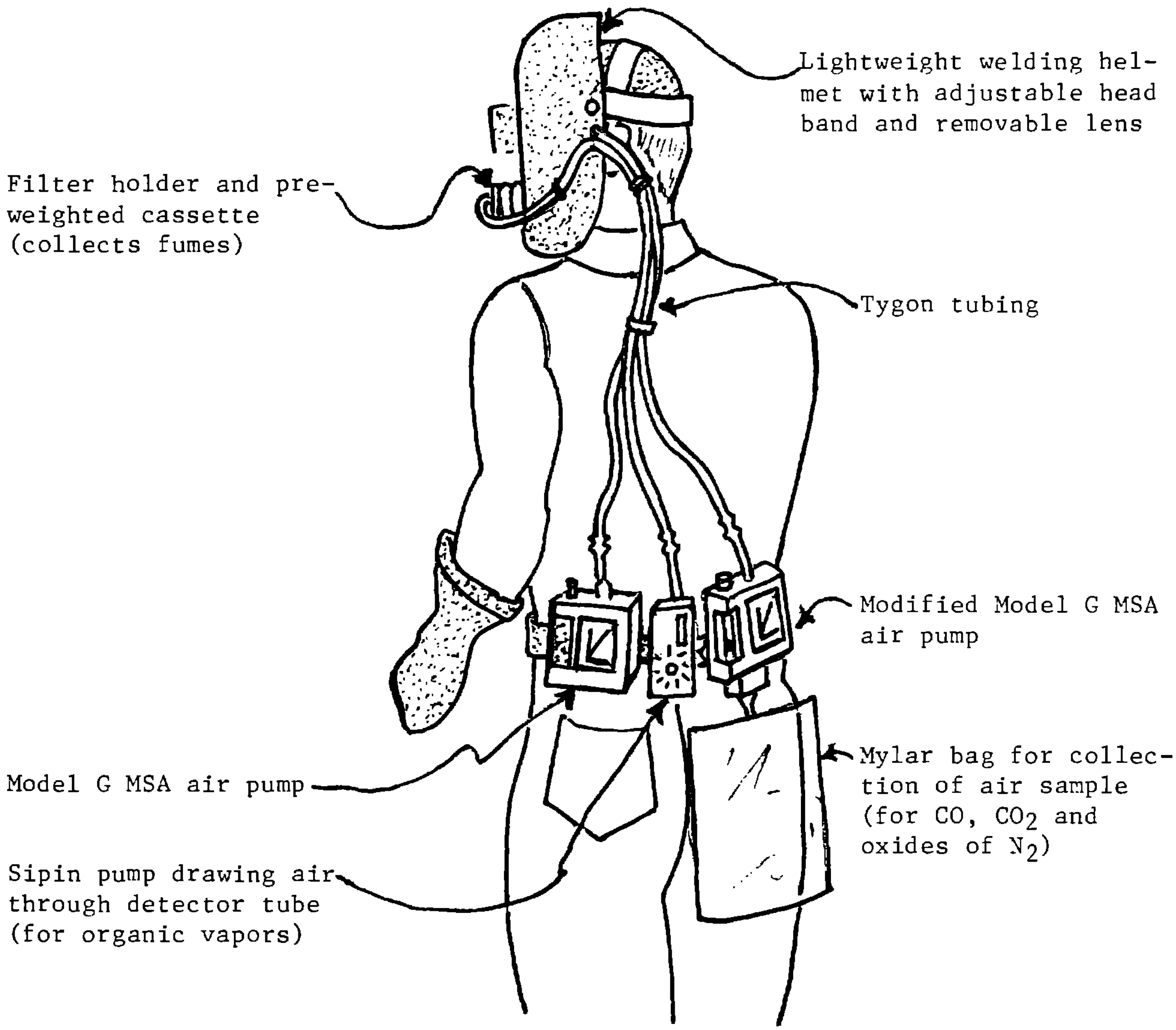
Dr. Stern is now conducting experimental work to isolate and identify components of the fumes which are mutagenic and/or contribute to possible synergism.

SAMPLING AND ANALYSIS OF WELDING FUMES AND GASES

To protect the welder's health, collection and measurement of the fume and gas concentrations both in the welder's breathing zone (inside his hood) and in his general work area are necessary. Particulate fume is filtered out on a suitable cassette fastened inside the hood in the welder's breathing zone. Gases may be detected or collected by either 1) NIOSH certified detector tubes fastened inside the welder's hood, 2) "spill-proof" impingers fastened on welder's belt or shirt, and 3) gas bags fastened to the welder's belt. Special portable pumps (attached to the welder's belt with suitable tubing connecting to the collectors) draw the contaminated air through the filter and/or collectors at a measured rate. Figure 1 pictures how an industrial hygienist would equip the welder to obtain the necessary samples. Sample collection continues while the welder operates as normally as possible. Fume sampling procedures are detailed by the AWS (13). Following collection, the fume and gas samples are analyzed for specific chemical content, usually by atomic absorption and/or wet chemical analytical methods (14).

For the industrial welding plant work presented in this NIOSH report, only fume samples were taken. These samples were collected on preweighted cassettes equipped with 37 mm vinyl chloride-acrylonitrile copolymer filters, 0.8 μm pore size. The Mine Safety Appliances Company (MSA) portable pumps (Model G) were calibrated by the NIOSH Equipment Maintenance and Calibration Section, Measurements Support Branch, Division of Physical Sciences and Engineering, for a flow rate of 1.8 lpm. Atomic absorption analysis for individual chemical compounds was performed by the Measurement Service Section of the same brand and division. After the total weight of each filter was determined, the filters (with fume contents) were ashed with distilled nitric acid. Subsequently, the metal contents (iron, nickel, copper, chromium, aluminum, and zinc) were determined, using atomic absorption spectrophotometric method P&CAM173 (14).

Figure 1. Evaluation of exposure to welding emissions utilizing modified personal sampling equipment. (Breathing zone measurements inside the mask)



NOTE: All these sampling devices would normally not be used simultaneously on an individual welder. In this study, only the fume cassette with requisite MSA air pump was employed.

INDUSTRIAL WELDING PLANT

GENERAL

This experimental work was conducted in the General Tool Company plant, Reading, Ohio, a large diversified job-shop. Their forte is high quality general fabrication of pressure vessels and intricate experimental equipment (custom made for large manufacturers and the Federal government). Nine welders operate in individual booths (each approximately 22' x 15' in floor area) separated from each other by movable welding curtains (Figure 2).

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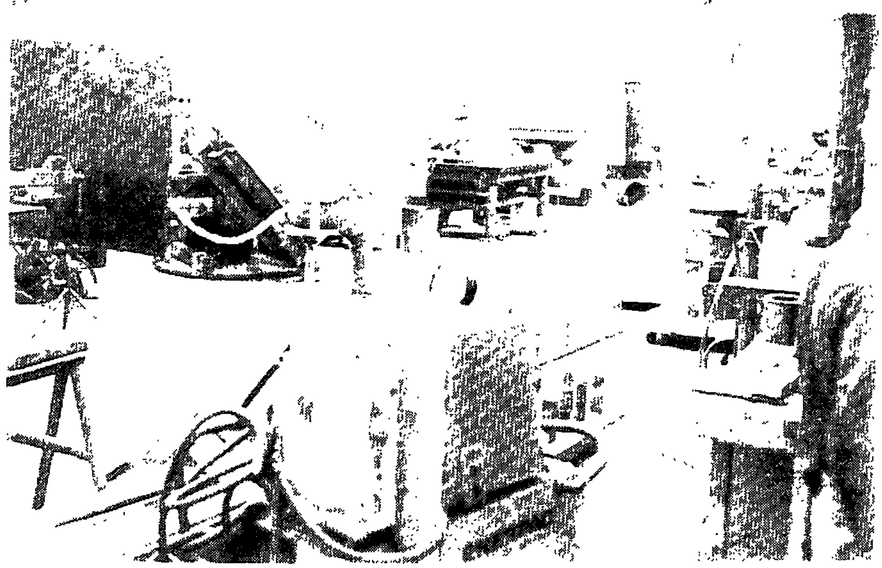

Figure 2. Illustration of booths separated by movable welding curtains.

These men are basically fabricators working from blue prints to make the required assemblies and using a variety of other equipment in addition to the welding units. The ceilings of the fabrication and welding wing of the plant are approximately 20' high to accomodate the chain lifts and electrically operated movable hoists employed to move and rotate the heavier assemblies. Regardless of the complexity of the assemblies, welding is done in the horizontal plane whenever possible. This ensures welding quality which will pass rigorous hydrostatic and air pressure tests -- zero leakage is required. In each booth, the welder works on either a massive 4' x 6' steel welding table or a weld positioner (3-dimensional movement).

General dilution ventilation is obtained from two sources, large exhaust fans located in the roof above the welding area and (for hot weather operation) two large multi-ton air conditioning units. Suitable ducting along the walls of the fabrication and welding bay dispenses the conditioned air uniformly. Because of the excellent dilution ventilation, nature of the fabrication work, and presence of the movable hoists and their rails, no local ventilation means are currently employed.

TYPES OF WELDING, WELDING UNITS, AND MATERIALS OF CONSTRUCTION

The majority of General Tool's welding is done on mild steel, but both stainless steel and aluminum are handled in large quantities as well as some galvanized steel. Semi-automatic MIG welding is primarily employed (particularly on mild steel). However, depending on metal thickness, complexity of fabrication, etc., TIG welding is also used when appropriate. Table 2 provides details of the welding equipment and its operating characteristics.

Table 2. General Tool Company welding equipment and operating characteristics.

Welding Type	Semi-Continuous MIG	Stick TIG
Welder	Miller Multipurpose DC Model Combo 600S	Lincoln Ideal-arc welder
Current	DC	DC
Polarity	Reverse	--*
Primary Circuit		
Voltage	230	--*
Current rating (amperes)	600 with carbon dioxide 300 with Argon	--* --*
Secondary Circuit		
Voltage drop (at arc)	25 - 40	--*
Current usage (amperes)	30 - 40	--*
Inert Gas	98% Argon-2% Oxygen	98% Argon-2% Oxygen
Gas Rate	30 - 35 cu ft/hour	30 - 35 cu ft/hour
Wirefeeder	Miller Model R-30	Stick
Wire and Wire Feed Rate	1/16" (0.062") copper coated (rolls), approx. 200" per min	Stick

Percent Composition for both MIG and TIG	Base Metal Mild Steel-Spec. C-1020	Electrode Steel Wire (copper-coated Spec. E.705-1B)
Carbon (C)	0.18 - 0.23	0.10
Manganese (M_n)	0.35 - 0.60	1.9
Phosphorous (P)	0.004 Max.	0.015
Sulphur (S)	0.005 Max.	0.016
Silicon (Si)	--	0.068
Nickel (Ni)	--	0.056
Molybdenum (Mo)	--	0.51

*Data not obtained.

SPECIFIC EQUIPMENT USED FOR EXPERIMENTAL WORK

DILUTION AIR DIRECTIONAL MOVEMENT EXPERIMENTS

To measure air flow direction and velocity, a Sierra Air Meter (Model 411-reading linear air velocity directly in fpm)was employed. Directional air flow was generated over the cross sectional area of the 4' x 6' welding tables or weld positioners by a Frigid (14" blade size) 3-blade table fan. This fan was equipped with a 35" pedestal mounting. To maintain constant levels of air flow, the fan rpm's was controlled by a voltage regulating variac. The fan was mounted at a vertical height of 5 - 6 feet and situated at a horizontal distance of 10 - 15 feet from the welding table and/or weld positioner.

"SMOKE EXHAUST" WELDING GUN EXPERIMENTAL TRIAL

"Smoke exhaust" welding guns, now being manufactured by several suppliers, are a means of local ventilation which have been especially designed for application to gas metal and/or flux core arc welding processes using semi-automatic or automatic wire feeding. A complete system includes 1) a gun and cable assembly, 2) a gun to feeder adapter kit, and 3) a vacuum pump and filter assembly. The particular model tested was the latest Hobart experimental design, the CSEG-600 Model (concentric 600 ampere "smoke exhaust"). As illustrated in Figure 3, this gun is different from the normal gas shielded models. A vacuum pump draws fumes and gases (generated at the welding site) through the concentric annular ring area of the welding gun without disturbing the inner shielding gas stream.

The "smoke exhaust" welding gun has a finger activated trigger which permits quick shifting from normal suction flow of 45 - 50 cubic feet per hour (cfh) down to 35 cfh. Since at least a 1:1 ratio of shielding gas flow to suction flow is required for weld "integrity," the General Tool Company normal usage of 30 - 35 cfh of 98% argon - 2% oxygen shield gas had to be increased to 50 - 55 cfh. While these flows maintained weld "integrity" in flat surface welding, satisfactory welds in angle shapes and particularly corners required reducing suction flow to 35 cfh while maintaining shielding gas flow at 50 cfh. A detailed discussion of the design, operation and results obtained by Hobart investigators using their "smoke exhaust" welding gun is reported in Welding Journal, June 1974 (15).

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Figure 3. Smoke exhaust system for gas metal-arc welding and flux cored arc welding.

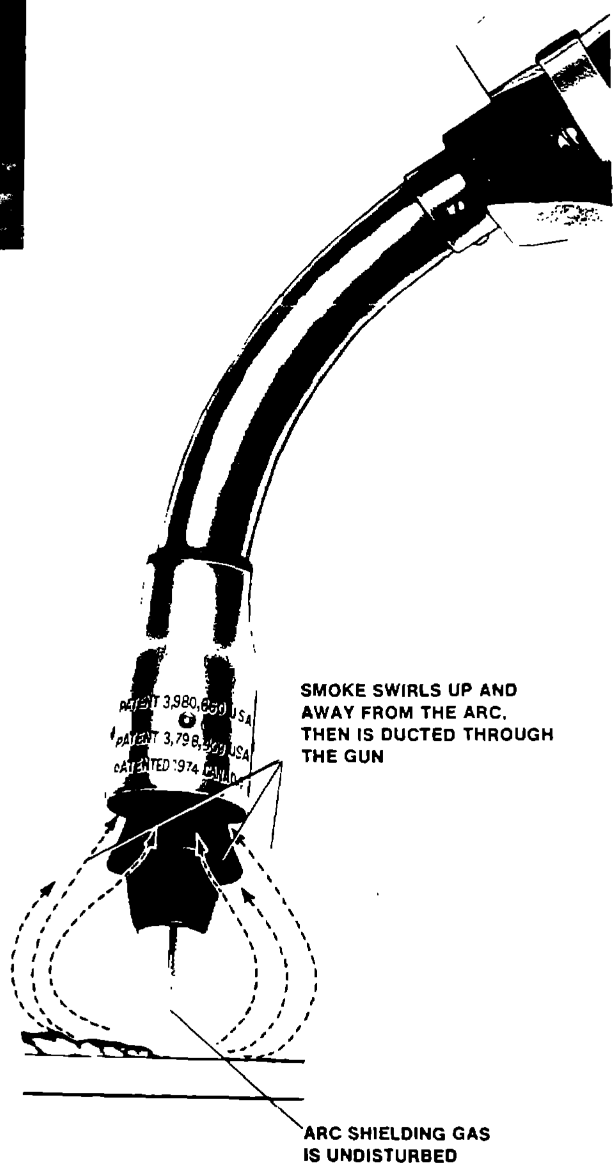
WITHOUT SMOKE EXTRACTION

WITH SMOKE EXTRACTION

ADVANTAGES

- Reduces smoke level markedly
- Eliminates repositioning of separate exhaust duct
- Internal air flow cools gun
- Amount of exhaust air is small portion of normal local ventilation system

(Smoke exhaust gun and pictures reproduced with permission from Hobart Brothers Company)



EXPERIMENTAL RESULTS

DILUTION AIR DIRECTIONAL MOVEMENT EXPERIMENTS

A somewhat controversial means of local ventilation is use of a local fan (fixed or portable) to blow welding fumes away from the welder's hood as the fumes rise from the welding site. Hence, there is fume dispersal which can help the welder but also may adversely effect the adjacent worker. The writer has personally observed favorable results with cross flow (90° to the welder) by a stationary fan. This was on a truck body manufacturing assembly line where the welder operated in essentially a fixed position doing repetitive welding. Sometimes portable fans are placed directly behind the welder blowing towards him on the apparent assumption this is the best direction for positive air flow to move fumes without affecting weld integrity.

In starting this experimental work, two preliminary questions had to be answered: First, what were the actual air flow conditions over the 4' x 6' welding tables before any added linear air flow was introduced through fan operation. Second, just what maximum air velocity could be tolerated over the welding site before weld integrity was endangered? An English reference (6) states "a wind speed over the weld of about 1 meter per second (approximately 200 fpm) is sufficient to reduce fumes without detriment to the weld."

Anemometer measurements over the cross sectional areas of the tables and their immediate vicinity demonstrated that ambient air flow lay in 0 - 50 feet per minute range and had a multidirectional pattern. These measurements were taken on a hot summer day when both air conditioners were operating at full capacity and all doors and windows securely closed. The readings emphasize air movement throughout the area was essentially uniform. Excellent duct, louvre, and baffle design and adjustment are apparent. The ventilation manuals state that satisfactory dilution ventilation will keep area particulate levels under 2 mg/m^3 for most welding operations. During this entire experimental welding study, 8-hour time weighted average (TWA) area samples tested under 0.6 mg/m^3. This level, for area samples taken within 6 - 10 feet of the individual welders, demonstrates excellent dilution ventilation. When positive linear air flow in a 50 - 200 fpm flow range was superimposed through fan operation, the air movement over the entire cross-sectional areas of the welding tables was reasonably uniform in velocity and linear in direction.

The veteran and acutely quality conscious welders were individually checked at their assigned welding tables for maximum tolerable air velocity across the welding site. At no time did they know the actual measured air velocities. Their individual judgements on maximum tolerable air flow (not adversely affecting weld "integrity") fell in a 75 - 100 fpm air velocity range. During this air velocity testing and later directional air movement experiments, all the welders performed flat surface semi-continuous MIG welding using 30 - 35 cubic feet per hour shielding gas (98% argon, 2% oxygen) flow on their welding guns. Their judgements were admittedly subjective but based on extensive experience. The unanimity of agreement was impressive. Hence, for the air direction experiment, maximum linear air flow during welding was regulated at 100 fpm (approximately 3/4 mile per hour).

The directional air flow experiments provide a comparison of 1) no local fan directed air flow, 2) cross draft air flow (90^{o} to the welder), and 3) air flow from directly behind the welder. Area samples, taken 6 - 10 feet from the welders, provide the 8-hour TWA values for the working areas. Breathing zone samples, collected inside the welder's hood only during the period when actual welding occurred, represent the short term exposure (STEL). Breathing zone TWA values were calculated as 8-hour averages of breathing zone STEL and area TWA values. Table 3 summarizes fume values for the directional air movement experiments (total fume basis expressed as mg/m^3). A complete tabulation of the data is appended as Appendix A.

These fume concentration results are not nearly as consistent as the data reported in Battelle's draft final report (16), but the trends are similar. (NOTE: Battelle's draft final report "Experimental Studies of Ventilation of Welding Fumes and Gases" had just been received prior to writing of this NIOSH report.) This greater variation had been anticipated since the Battelle results are based on rigorous laboratory control with the welder operating in a set position and repeating the same welding task. In contrast, in the plant situation, the welder operated the majority of the time in a single directional relationship with the table and the constant 100 fpm air flow, but the remainder of the time, fabrication required him either to take different positions and/or move partially around the table. Regardless of the welder's shifting movements, the fan position was left unchanged and the air flow maintained constant. STEL results, in particular, confirm Battelle's conclusion that cross draft air movement can be beneficial to the welder when he can constantly maintain a position at 90^{o} to the air flow. However, positive air flow from directly behind the welder may cause equivalent or even higher breathing zone fume concentration than if no directional air flow is employed. These results indicate that eddy and convection currents around the welders body adversely affect fume concentration in the welder's breathing zone.

Close examination of the calculated concentrations of individual metals in the welder's breathing zone (Appendix A) demonstrates that the maximum TLVs were only approached in one specific situation. This was for nickel and chromium fumes generated during stainless steel welding. The cause is not copious fume evolution but rather the strict limits for carcinogenic elements recommended recently by NIOSH (Table 1). Because of the nature of General Tool Company's work, the welders rarely weld more than two hours per 8-hour shift. This situation plus the low level of nickel and chromium content in stainless steel fume resulted in both welder's breathing zone and area samples containing insufficient nickel and chromium to provide conclusive analytical results. A Swedish welding plant survey (17) concluded that in stainless steel welding 60% of the MMA welders and 25% of the MIG and TIG welders are exposed to contaminant concentrations above the 5 mg/m^3 total fume concentration limit (Table 1) in their breathing zone. Also, over 90% of the MMA welders and over 50% of the MIG and TIG welders are exposed to hexavalent chromium (Cr_6) concentrations above the 0.05 mg/m^3 STEL NIOSH recommended limit.

Table 3. Fume concentrations for different directional air movements

Situation	Total Fume, mg/m^3 Welding Table	Weld Positioner
• No Fan Directed Airflow	0.15	0.30
Area Concentration	0.15	0.30
Breathing Zone Concentration		
STEL	5.8	26.2
TWA	1.2	2.5
• Cross Draft (90° to welders)		
Area Concentration	0.50	0.11
Breathing Zone Concentration		
STEL	4.0	1.9
TWA	1.2	0.6
• Air Flow from Directly Behind Welder's Back		
Area Concentration	0.55	0.55
Breathing Zone Concentration		
STEL	10.1	5.4
TWA	2.3	1.7

"SMOKE EXHAUST" WELDING GUN EXPERIMENTAL TRIALS

A single experimental "smoke exhaust" gun (provided by the Hobart Brothers Company, Troy, Ohio) was tested by one welder on two consecutive days doing mild steel fabrication work on a welding table. For direct comparison of results with those from the earlier air direction trials, this welder operated in his booth making duplicates of the earlier fabrications. By this means a valid comparison was assured - something difficult to achieve under normal job-shop scheduling. The "smoke exhaust" gun was adapted to the same equipment previously employed. Table 4 provides a total fume concentration comparison of a regular gun vs. the "smoke exhaust" gun in MIG welding of mild steel (no fan directed air flow).

On a visual comparison, the "smoke exhaust" gun appeared to provide a major improvement in fume control. This was evident particularly during flat surface welding. Fume removal by the "smoke exhaust" welding gun was less successful (visual appearance) when suction flow had to be reduced from 50 to 35 cubic feet per hour to maintain the gas shield and weld "integrity" while welding in angle sections and corners. Based on the STEL total fume concentration figures from Table 4, overall fume reduction in the welder's breathing zone approximated 78%. Comparison of STEL values is valid since the "smoke exhaust" welding gun suction functions only during actual welding.

Table 4. Fume concentrations - Regular vs. "Smoke Exhaust" welding guns.

	Total Fumes, mg/m^3			
Welding Gun Type	Regular Gun	"Smoke Exhaust" Gun		
		1st day	2nd day	Average
Area Concentration	0.15	0.40	0.49	0.45
Breathing Zone Concentration				
STEL	5.8	1.1	1.4	1.25
TWA	1.2	0.62	0.66	0.64

To double check the validity of this performance comparison, Table 5 presents calculated concentrations (mg/m^3) of ferric oxide (Fe_2O_3) - the principal component of fumes evolving from MIG welding of mild steel. The ferric oxide fume reduction obtained through use of the "smoke exhaust" gun approximated 72%. In the literature reference (15), fume and gas removal of 80 to 100% was reported for the Hobart "smoke exhaust" welding gun. The difference in level of that fume removal efficiency when compared with that from the NIOSH trial may be attributable to the higher proportion of angle and corner welding required in the General Tool Company fabrication work.

Table 5. Fe_2O_3 content in welding fumes - Regular vs. "Smoke Exhaust" welding gun

Welding Gun Type	Fe_2O_3 Fumes, mg/m^3			
	Regular Gun	"Smoke Exhaust" Gun		
		1st day	2nd day	Average
Area Concentration	0.07	0.12	0.23	0.17
Breathing Zone Concentration				
STEL	3.38	0.69	1.20	0.95
TWA	0.66	0.30	0.41	0.36

While the "smoke exhaust" welding gun is a successful technical innovation for fume and gas control during semi-continuous and continuous flux core and MIG welding, there are negative aspects which must be clearly recognized.

- The gun is bulkier than a regular welding gun. This makes welding more difficult and in some tight corners almost impossible.
- Gun weight is greater than for a regular welding gun. The welder particularly disliked this effect when welding demanded extra physical exertion.
- The welder must clean the "smoke exhaust" gun more frequently. Fume passage through the nozzle suction annular orifice causes clogging, hence cleaning time is approximately doubles vs. that of a regular welding gun.
- The "smoke exhaust" welding gun is normally operated with an adjacent particulate filter to maintain local air quality. The Hobart filtration unit needs major improvement for routine long term gun use. Also, welders resent cleaning filters; they regard themselves as skilled craftmen.
- Cost of shielding gas rises with use of the "smoke exhaust" gun in the ratio of 50 cfh vs. 35 cfh (for normal MIG gun shielding gas flow).
- Engineering design features of this experimental gun need upgrading. (The welder had useful suggestions which were passed to the Hobart engineering staff.)
- A reduced vacuum warning mechanism is considered a necessity for successful routine "smoke exhaust" welding gun operation.

Unfortunately, this "smoke exhaust" gun experimental trial left an important question unanswered - will a "smoke exhaust" welding gun provide adequate local ventilation to maintain nickel and hexavalent chromium fume concentrations in the welder's breathing zone below the NIOSH proposed limits for carcinogenic agents? Further experimental work is needed to answer this question. Conclusions of the Swedish plant survey (17) are very disquieting as to this aspect. The writer's objective judgement is that a "smoke exhaust" welding gun, when properly maintained, is the best available means of local ventilation for applicable welding processes.

CONCLUSIONS

Maximum air flow across a weld site in MIG welding should not exceed 100 fpm linear volocity in order to maintain weld "integrity." This generalization holds whether the air flow is local fan generated, directional air flow, or arises from plant general dilution ventilation.

The NIOSH commercial welding plant study validates Battelle's conclusions (based on rigorously controlled laboratory experimentation) on effect of dilution air direction (in relationship to the welder) vs. fume concentration in the welder's breathing zone.

- Cross draft airflow (not over 100 fpm at 90° to the welder) significantly lowers breathing zone fume concentration from that prevailing when no directional air flow is employed.

- With directional air flow coming from directly behind the welder's back, the welder's breathing zone fume concentration may be equal to, or higher than, that prevailing when no directional air flow is employed.

- Study of these welding operations has convinced the writer that only limited situations in commercial welding permit the welder to function in a constant position relative to directional air flow generated by a local fan.

A "fume exhaust" welding gun (with related accessories) can do a satisfactory job of fume removal from the welding site in continuous or semi-continuous flux core or MIG welding operation. Fume removal efficiency is greatest in flat surface welding and drops off when welding in angle or corner situations. Seventy to eighty percent reduction in fume concentration in the welder's breathing zone seems entirely feasible if the "fume exhaust" gun and related accessories are maintained at peak efficiency.

For commercial plant welding situations, typified by the General Tool Company operation, the "fume exhaust" gun is the most practical effective means of local exhaust ventilation for welding of galvanized or stainless steels.

This plant investigation indicates that in well designed welding shops that meet ANSI Z49.1-1973 Ventilation Guidelines, fume concentrations in the welder's breathing zone normally do not exceed the threshold value time weighted average limits (TLV-TWA) for any of the shop welders. Problem situations are 1) meeting STEL limits during periods of steady and intense welding when employing welding processes generating high fume and gas concentrations and 2) meeting TWA limits with welding materials containing carcinogenic components.

- In the first case, installation and careful use of efficient local ventilation in addition to satisfactory general dilution ventilation can maintain satisfactory low STELs for all the shop welders.

- The latter case, typified by stainless steel weldings, is more difficult from the standpoint of protecting the long term health of welders. Depending on the individual situation, in addition to optimum dilution and local ventilation facilities, wearing of personal protective equipment may be essential during welding (preferably a positive pressure air supplied breathing apparatus-hood combination).

- For personal protective equipment selection, reference should be made to the OSHA Safety and Health Standard 29 CFR 1910.134 (Respiratory Protection) and the available and recommended ANSI-Z28, 2-1969, Cartridge Respiratory Protection Equipment.

RECOMMENDATIONS

- In most welding situations, use of portable fans as a means of local ventilation is not recommended. An exception would be for a welder doing repetitive welding in an essentially fixed position. In such case, cross draft air flow (controlled at less than 100 fpm velocity at 90° to the welder) would be beneficial.

- Further experimental work on stainless steel welding in commercial welding plants is needed to clearly establish whether nickel and chromium fume concentrations in the welder's breathing zone (TWA and STEL values) would exceed NIOSH recommendations for carcinogenic agents when 1) optimum general dilution and local ventilation are employed and 2) a "smoke exhaust" gun is the means of local ventilation.

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APPENDIX A. Calculated Results for Welding Survey

(A) Fume and Metal Concentrations in Welder's Breathing Zone for Different Directional Air Movements

SITUATION	FLAT WELDING TABLE: Total Fume (mg/m^3)	FLAT WELDING TABLE: % of Total Fume Accounted for by Metal Analysis	FLAT WELDING TABLE: Metallic Conc. (mg/m^3) Iron (Fe_2O_3)	FLAT WELDING TABLE: Metallic Conc. (mg/m^3) Copper (Cu)	WELDING POSITIONER: Total Fume (mg/m^3)	WELDING POSITIONER: % of Total Fume Accounted for by Metal Analysis	WELDING POSITIONER: Metallic Concentrations (mg/m^3) Iron (Fe_2O_3)	Copper (Cu)	Aluminum (Al_2O_3)	Zinc (ZnO)	Nickel (Ni)	Chromium (Cr)
NO FAN DIRECTED AIR FLOW												
Area Concentration	0.15	(48.8)	0.07	-	0.30	(41.6)	0.05	0.003	0.04	0.001	<0.002	<0.002
Breathing Zone Concentration												
STEL	5.8	(54.8)	3.38	0.08	26.2	(58.1)	0.26	-	15.[illegible]	-	<0.026	<0.026
TWA*	1.2	(49.8)	0.66	-	2.54	(43.7)	0.06	-	1.33	-	<0.004	<0.004
CROSS DRAFT (100' min 90° to welder)												
Area Concentration	0.42	(48.8)	0.24	0.01	0.11	(41.6)	0.04	0.003		0.001	<0.002	<0.002
Breathing Zone Concentration												
STEL	4.0	(53.5)	2.[illegible]	0.06	1.9	(53.6)	[illegible].0	0.017	-	0.03	<0.01	<0.01
TWA*	1.2	(46.5)	0.60	0.02	0.6	(45.4)	0.29	0.006	-	0.008	<0.004	<0.004
AIR FLOW FROM DIRECTLY BEHIND WELDER (100' per min)												
Area Concentration	0.55	(10.3)	0.06	0.001	0.55	(7.9)	0.04	0.002	-	-	-	-
Breathing Zone Concentration												
STEL	10.1	(29.5)	3.0	0.07	5.4	(54.5)	2.9	0.05	-	-	-	-
TWA*	2.5	(13.7)	0.59	0.013	1.69	(18.9)	0.71	0.014	-	-	-	-
LIMITS (mg/m^3) 1977 ACGIH and/or Oct 77 NIOSH (see Table I)												
STEL	No Limit	-	10	No Limit	No Limit	-	10	No Limit	20	10	No Limit	0.05 Carcinogenic Cr_6
TWA	5	-	5	0.2	5	-	5	0.2	10	5	0.015	0.001 " " ; 0.025 Non-carcinogenic Cr_6

(B) Fume and Metal Concentrations in Welder's Breathing Zone for Regular vs. 'Smoke Exhaust' Welding Gun

SITUATION	Total Fume (mg/m^3)	% of Total Fume Accounted for by Metal Analysis	Iron (Fe_2O_3)	Copper (Cu)	Total Fume (mg/m^3)	% of Total Fume Accounted for by Metal Analysis	Iron (Fe_2O_3)	Copper (Cu)	Aluminum (Al_2O_3)	Zinc (ZnO)	Nickel (Ni)	Chromium (Cr)
REGULAR GUN (mg/m^3)	(FLAT WELDING TABLE ONLY)											
Area Concentration	0.15	(48.8)	0.07	-								
Breathing Zone Concentration												
STEL	5.8	(54.0)	3.38	0.08								
TWA*	1.2	(49.8)	0.66	-								
FUME GUN (mg/m^3)	FIRST DAY				SECOND DAY							
Area Concentration	0.40	(35.0)	0.12	0.01	0.49	(48.2)	0.23	0.004	-	-	-	-
Breathing Zone Concentration												
STEL	1.1	(64.9)	0.69	0.02	[illegible].4	(9[illegible].7)	[illegible].2	0.04	-	-	-	-
TWA*	0.62	(44.4)	0.30	0.012	0.66	(56.4)	0.41	0.002	-	-	-	-

*Calculations from STEL & Area Data.

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