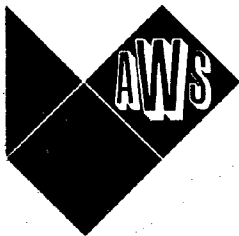


Welding Fume Control:

A Demonstration Project



AMERICAN WELDING SOCIETY

Welding Fume Control: A Demonstration Project

Evaluation of the Effectiveness and Applicability of Selected Ventilation Controls and an Air Purifying Helmet for Welding Applications.

Research performed by the Rexnord Corporation at its Environmental Research Center under contract with the American Welding Society and supported by industry contributions.

Prepared for:
Safety and Health Committee
AMERICAN WELDING SOCIETY
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Printed in the United States of America

Contents

<i>Personnel</i>	v
<i>Acknowledgements</i>	vii
<i>Abstract</i>	xi
<i>Acknowledgement</i>	xiii
<i>Section 1 Introduction</i>	1
Past Research	1
Study Objective	1
Devices Evaluated	2
Evaluation of Ventilation Control	2
Evaluation of the Air Purifying Helmet	7
Testing Facility	7
<i>Section 2 Conclusions</i>	8
<i>Section 3 Recommendations</i>	11
<i>Section 4 Discussion</i>	11
Usefulness of Controlled Test Results	11
Need for Additional Industrial Assessment	11
Evaluation of Control Measures for Other Processes	12
Measuring Welders' Exposures	12
<i>Section 5 Testing Procedures and Measurement Methods</i>	12
Welding Procedures	12
Use of Control Devices	14
Simulation of Open and Confined Space Conditions	16
Air Sampling Program	16
<i>Section 6 Evaluation of Effectiveness</i>	22
Introduction	22
Exposure Reduction for Ventilation Controls	22
Protection Factor for Air Purifying Helmet	25
<i>Section 7 Evaluation of Applicability</i>	26
Usability	26
Reliability	26
Effect on Process	27
Impact on Productivity	27
Worker Acceptance	31
<i>References</i>	32
<i>Appendix A: Breathing Zone and Area Concentration Averages and Ranges for Selected Fume Constituents</i>	33
<i>Appendix B: Statistical Summary of Breathing Zone and Area Sampling Results for the Various Fume Constituents</i>	41
<i>Appendix C: Correlations Among Fume Constituents</i>	55
<i>Appendix D: Lapel Versus In-Helmet Sampling Results</i>	63
<i>Appendix E: Chemical Analysis of Fume</i>	65

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Acknowledgements

The American Welding Society gratefully acknowledges the time and effort expended by the members of the Research Committee and the financial support of the program by industry contributions.

Supporting Organizations

Air Products and Chemicals, Inc.
Airco Welding Products
Allis - Chalmers
Alloy Rods Division, The Chemetron Corporation
AWS Detroit Section
AWS New Orleans Section
Arcos Corporation
The Blinkley Company
Caterpillar Tractor Company
Chicago Bridge and Iron Company
Grove Manufacturing Company, Division of Kidde, Inc.
General Electric Company
The Heil Company
Hobart Brothers Company
Huntington Alloys, Inc.
Lincoln Electric Company
Miller Electric Manufacturing Company
National - Standard Company
A.O. Smith Corporation
Teledyne - McKay, Inc.
Trinity Industries, Inc.
Truck Trailer Manufacturers Association
Walker Stainless Equipment Company
Weld Tooling Corporation

Many other organizations have made contributions to support the ongoing program from May 1979 to the present.

Evaluation of the Effectiveness and Applicability of Selected Ventilation Controls and an Air Purifying Helmet for Welding Applications

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Abstract

This report presents the results of a welding fume control demonstration project performed for the American Welding Society. The study evaluated the effectiveness and applicability of three different types of commercially available exhaust methods for control of welding fume at the source during shielded metal arc welding. The three methods evaluated, all of them mobile methods, included high volume exhaust, high velocity, low volume (HVLV), and the handheld shield.

Of particular interest in the study was determination of whether use of these control measures would result in reduction of worker exposures to toxic metals such as nickel and hexavalent chromium to the low limits being considered by OSHA. Besides the exhaust control measures, the protection offered by an air purifying helmet was also studied.

The tests were conducted under controlled conditions in a simulated industrial setting using stainless steel base metal and electrodes. The results showed that each of the exhaust control measures studied, if used properly, was capable of substantially reducing breathing zone and general area concentrations of welding generated contaminants in both open and confined spaces. However, even with consistent usage and proper positioning, not all of the limits being considered by OSHA for hexavalent chromium were met. Not even the air purifying helmet met all the limits being considered. The limit being considered for nickel was met in many cases.

The study of applicability identified the attributes and deficiencies of the various methods. It must be remembered in interpreting the results of these evaluations, however, that the test conditions were established to represent common industrial welding operations, not worst case conditions. A useful followup for this study would be to establish, on the basis of field evaluations, limiting constraints for the use of each of these methods and selection and design criteria using a system approach. It would also be useful to extend these controlled experiments to the gas shielded arc welding process.

Acknowledgement

Our gratitude is extended to the Harnischfeger Corporation - Milwaukee for providing floor space at their Corporate Manufacturing Training Center to house the experiments, and supplying welding personnel for performing the welding during the tests. A special thanks is also due to the Arcos Corporation for supplying the electrodes and Crucible Inc., who supplied the stainless steel base metal used in the tests.

John Hinrichs, Paul Ramsey, and Gene Wiggs of the Safety and Health Committee, American Welding Society, provided invaluable guidance and help throughout the study.

Funds for this project were provided by the American Welding Society.



Welding Fume Control: A Demonstration Project

SECTION 1 INTRODUCTION

PAST RESEARCH

Both industry and governmental agencies have been active in research efforts to determine worker exposure to contaminants generated by welding and to develop appropriate ventilation controls. Early research was directed primarily at quantifying the welder's exposure under different conditions, e.g., in open versus confined space, using different types of welding, with or without localized and general ventilation (Refs. 1, 2, 3, 4, and 5).

Recent studies by the American Welding Society (AWS) and the National Institute for Occupational Safety and Health (NIOSH) have been aimed at methods for assessing the welder's exposure and design criteria for local and general ventilation systems. *The Welding Environment*, published by the AWS, provided the following useful information (Ref. 6):

- (1) The type and amount of particulate and gaseous contaminants resulting from commonly used electrodes.
- (2) The manner in which fume composition from selected electrodes is affected by different manufacturing techniques.
- (3) The development of a standard method for sampling airborne particulate in the welding environment. This information was later published as a separate document (Ref. 7).

In a second AWS publication, entitled *Fumes and Gases in the Welding Environment*, data were presented to enable ventilation engineers to design effective systems for capturing welding fume (Ref. 8). These

data were generated under closely controlled, open space conditions within a laboratory. The publication addressed both general and local exhaust ventilation methods, and their effects on each other. Both theoretical and experimental results were used to characterize the effect of induced air velocity and exhaust volume on fume concentration within the welder's breathing zone. Several local exhaust configurations were tested, including portable flanged intakes of different diameters, a slotted exhaust inlet and an overhead canopy hood. Each of these configurations were custom built to the researcher's specifications. Fume and crossdraft simulators were used in the experiments.

A NIOSH published document entitled *Engineering Control of Welding Fumes* developed design criteria for local ventilation systems (Ref. 9). During this investigation, the effectiveness with which selected ventilation methods protected the welder from exposure to the fume was measured. These methods included a slotted backdraft hood similar to that presented in the Ventilation Manual of the American Conference of Governmental Industrial Hygienists (ACGIH) (Ref. 10), as well as a free standing, flanged, rectangular hood. Several types of welding processes were tested, including shielded metal arc welding (SMAW) and gas metal arc welding (GMAW). This research was similar to the AWS research in that the exhaust control methods were custom built and the tests were performed in open spaces in a laboratory setting.

STUDY OBJECTIVE

Recently, NIOSH has issued criteria for revised standards for occupational exposure to nickel and hexavalent chromium (Cr VI). NIOSH is recommending a reduction in the current permissible exposure limit (PEL) from 1,000 to 15 $\mu\text{g}/\text{m}^3$ for nickel and from 50

2/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

$\mu\text{g}/\text{m}^3$ for total Cr VI to $1 \mu\text{g}/\text{m}^3$ for certain water insoluble Cr VI compounds, and $25 \mu\text{g}/\text{m}^3$ for water soluble Cr VI (Ref. 12). The Occupational Safety and Health Administration (OSHA) is considering several options for the Cr VI PEL which include (Ref. 14):

- (1) $10 \mu\text{g}/\text{m}^3$ with a $25 \mu\text{g}/\text{m}^3$ ceiling.
- (2) $1 \mu\text{g}/\text{m}^3$ with a $10 \mu\text{g}/\text{m}^3$ ceiling.
- (3) The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or $50 \mu\text{g}/\text{m}^3$).

The question arises as to the technical feasibility of reducing nickel and chromium levels within the high alloy welding environment to these low standards using today's state-of-the-art ventilation control methods. It was the primary intent of this study to evaluate the effectiveness and applicability of three different types of commercially available local ventilation controls in reducing worker exposure to welding generated contaminants. In addition, a personal protective device (air purifying helmet), was also studied.

Tests were limited to shielded metal arc welding (SMAW) on stainless steel. Both open and confined space conditions were tested in a controlled environment within a welding research center. To establish a baseline for evaluation of the devices, tests were also conducted without the use of ventilation controls.

This demonstration study is intended to serve as a basis for further ventilation studies under a much wider range of production conditions.

DEVICES EVALUATED

The devices tested are listed in Table 1-1; specifications are presented in Table 1-2. Photographs of each of the devices are presented in Figs. 1-1 through 1-5.

EVALUATION OF VENTILATION CONTROL

The primary emphasis in the study was directed at assessing the effectiveness of the control measures. Besides effectiveness, other important aspects relating to the applicability of these control measures were also evaluated including: usability, reliability, effect on the process and worker acceptance. Specific design related considerations were not included in this evaluation, e.g., system size and weight, complexity, and power consumption; nor were costs considered. These latter factors, although important in the selection of a device for a specific application, should be addressed using a systems design approach.

*The OSHA standard is $100 \mu\text{g}/\text{m}^3$ for chromate (CrO_3) which on a weight basis equate to approximately $50 \mu\text{g}/\text{m}^3$ for CR VI alone.

Ventilation Effectiveness

A ventilation control has a twofold role of preventing the contaminants from directly entering the breathing zone of the welder as well as protecting other personnel in the area. Effectiveness in protecting the breathing zone from welding generated contaminants was evaluated in this study using personal filter samples taken underneath the welding helmet. General area samples were taken to assess buildup in the workplace. It should be emphasized here that effectiveness, as defined above, is different than capture hood efficiency. Capture hood efficiency is defined as the ratio of the amount of generated contaminant that is removed by the capture method to the total amount that is generated by the welding process. Effectiveness, on the other hand, is evaluated in terms of the control's ability to reduce breathing zone concentrations.

Usability

In industry, welding is performed in both production and maintenance applications on a wide variety of workpieces. The physical interferences which limit the applicability of a particular ventilation control measure may result from the size and limited mobility of the control measure itself or they may be due to the size and configuration of the workpiece or the room, compartment or vessel in which it is housed. All of the welding control methods evaluated in this study can be classified as mobile methods, i.e., they are capable of being repositioned as necessary to accommodate varying requirements of a job.

Another important aspect of usability relates to the ability of a control measure to maintain itself in the various positions required by the work. Even if physical interferences or lack of mobility do not limit access to the proper position needed for effective control, in a given situation the control measure may not be able to maintain the required position for effective capture itself. A control measure without the means for being properly positioned will not be used properly, if at all. The usability of these three control methods was assessed by subjecting them to tests requiring that they be used in various positions both in open areas and in confined spaces.

Reliability

There were two different factors explored in assessing the reliability of the control measures. The first aspect concerns the amount of worker interaction that is necessary for effective performance. The most desirable situation would be for the control method to be fully automatic with respect to the welding process and not require *any* worker involvement and very little maintenance. No such measure, however, was found for the shielded metal arc process (SMAW). Each control measure evaluated required some degree of worker involvement; the extent of that involvement

Table 1-1
Devices tested

Type	Description	Abbreviation	Figure no.
High volume	Two types evaluated:	Hi-Vol	1-1
	(1) Flexible hose with suction hood; hood repositioning mechanism consisting of adjustable support arms extending from movable platforms (for open spaces).		1-2
High velocity, low volume	Portable, "vacuum-cleaner" style pick-up with five different attachments.	HVLV	1-3
Handheld shield exhauster	A handheld pickup for use on the "HVLV" system, which has the viewing glass and face shield incorporated into the exhauster.	Hand shield	1-4
Air purifying helmet	A helmet consisting of a face shield, viewing glass, hard-hat and battery powered blower/filter.	APH	1-5

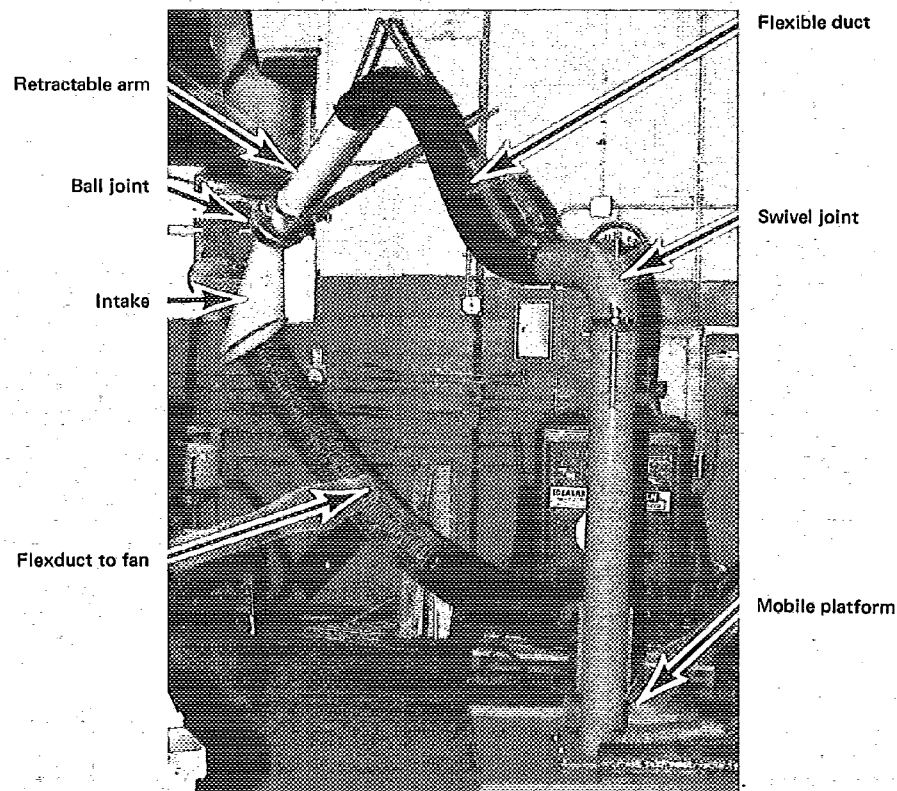


Fig. 1.1—High volume-open space exhauster

4/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table 1-2
Specifications for devices tested

High volume:

Airflow rate:	1000 cfm (0.47 m ³ /sec)
Duct diameter:	Open space — 5 in. (12.2 cm) Confined space — 8 in. (20.3 cm)
Intake size:	Open space — oval 10 x 15 in. (25.4 x 38.1 cm) Confined space — 8 in. (20.3 cm) square
Intake material:	Open space — fiberglass Confined space — galvanized sheet metal.
Reach:	Open space — 15 ft (4.6 m) Confined space — as long as flex duct.

High velocity, low volume:

Airflow rate:	Rated at 130 ft ³ /min (0.06 m ³ /sec) (rating conditions not specified). Using the blower and hoses supplied with the unit, and using 25 ft (7.6 m) on the inlet and 10 ft (3.1 m) on the outlet of the blower, the measured exhaust rate was 80 ft ³ /min (0.03 m ³ /sec).
Hose diameter:	1.75 in. (4.45 cm)
Blower type:	High pressure — 2 stage
Recommended arc to intake distance:	3/4 to 2 in. (1.9-5.1 cm)

Handheld shield:

The handheld shield was used with the portable HVLV blower system.

Air purifying helmet:

Airflow rate:	8 cfm (13.6 m ³ /Hr)
Noise:	70 dbA at wearer's ear
Filters:	HEPA (99.97% efficiency on DOP with 0.3 micron particle size).
Face protection:	Complies with ANSI Z87.1-1968.
Welding shield:	4-1/2 x 5-1/4 in. (11.4 x 13.4 cm) glass
Battery pack:	Ni Cad rechargeable, 8 hr continuous use per charge.
Weight:	Helmet and hose - 2.0 lbs (0.9 kg) Airflow module (with batteries and filters) - 3.9 lbs (1.8 kg)

and the susceptibility for the method to be improperly, and thus ineffectively, applied by the welder during the course of its use was thus evaluated.

The second aspect of reliability relates to the ability of a control to sustain its performance for a long period of time in severe industrial applications. Susceptibility to failure could arise, for example, because of a control method's potential for plugging, resulting in reduced air flow, and incomplete fume capture, or to physical damage to the hood, support systems, or ducting.

During this study, the worker interaction aspect of reliability was evaluated by giving a welder specific instructions on how to use the control properly and then assessing his performance as he attempted to carry out these instructions. The second aspect of reliability, however, was more difficult to assess because the controlled conditions and short duration of the tests did not allow ample opportunity for the kinds of failures to occur that might eventually occur in industrial applications. Thus, failure modes were evaluated by assessing possible causes of failure and noting any required maintenance procedures.

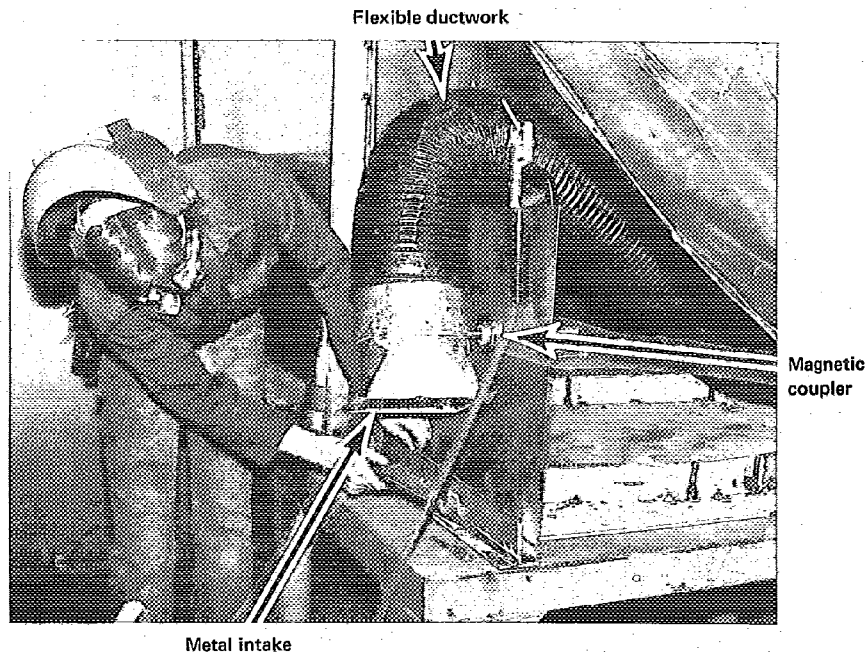


Fig. 1.2—High volume-confined space exhauster
(Posed picture; during tests welder wore safety glasses and gloves)

Effect on the Process

A ventilation control could affect the welding process by:

- (1) Affecting the ability of the welder to produce a weld of acceptable quality.
- (2) Slowing the welder down, thus reducing the production rate.
- (3) Adding unusual constraints that the welding procedure cannot tolerate.

As was indicated earlier, the ventilation control measures available for shielded metal arc welding do not function automatically. Rather, they require manual input from the welder, primarily to reposition the intakes to effectively capture the fume. The possibility exists that the welder could position the control either too far from or too close to the point of welding. If the distance is too great, ineffective capture results. If too close a distance is used, the possibility exists that the shielding atmosphere around the weld could be disrupted to the extent that welding quality would be affected. It is doubtful that adverse effects on weld quality resulted from the control methods used in this study. The welder reported that the controls caused no apparent changes in the welding process or the ultimate appearance of the weld. Had such changes been suspected, further tests would have been required to assess the extent of the disturbance.

The effect of a particular ventilation control on productivity was easier to assess. By having the worker perform a fixed protocol of welding operations, with and without the use of the control measure, permitted an assessment of potential reductions in productivity.

The possible addition of unusual constraints was also evaluated by maintaining close surveillance of the worker as he welded.

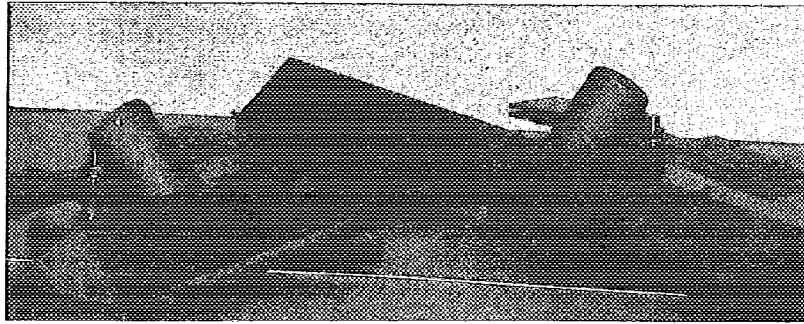
Worker Acceptance

Whether or not a particular control measure is accepted by the welder is dependent on many factors, both objective and subjective in nature. Three objective factors that represent physical requirements of every job, are critical to worker acceptance. These include:

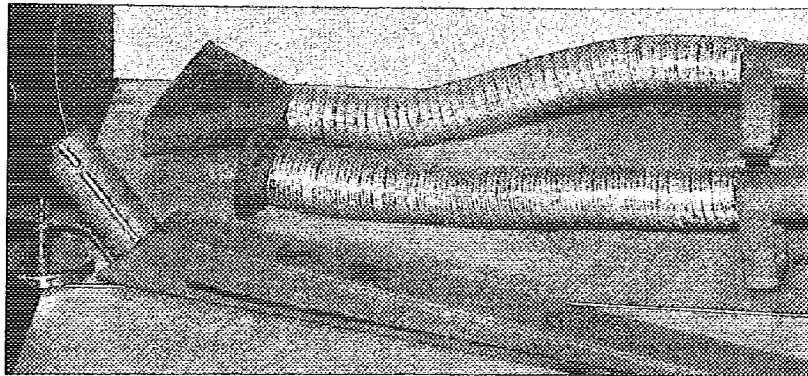
- (1) The amount of effort required to operate a control.
- (2) Any geometrical limitations that would prevent the worker from gaining safe access to and performing the work.
- (3) Anything that would obstruct the workers vision.

Other factors, more subjective in nature, center around the worker's basic attitude toward additional tasks associated with operating safety and health measures.

6/WELDING FUME CONTROL: A DEMONSTRATION PROJECT



Long and short stick nozzles



Side stick (foreground) and funnel nozzles

Fig. 1.3—High velocity low volume (HVLV) nozzles

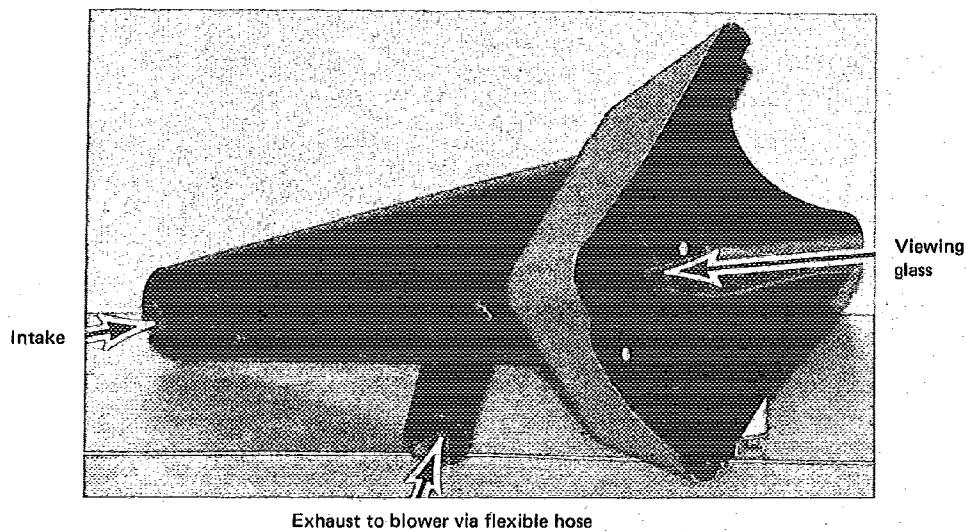


Fig. 1.4—Hand-held shield exhauster for use in an HVLV system

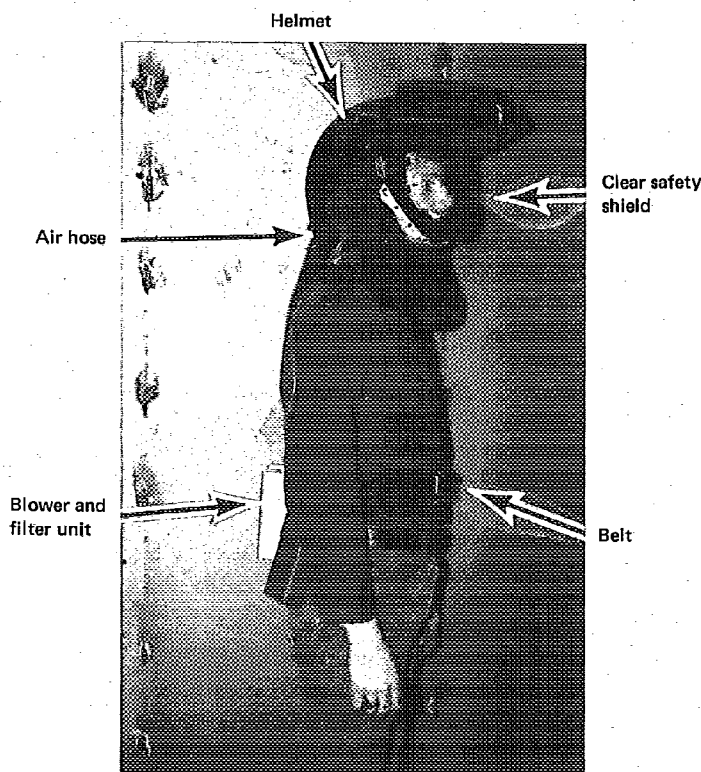


Fig. 1.5—Air purifying helmet - welding shield in raised position

In this study, worker acceptance was evaluated as follows. At the beginning of the testing, the welder was informed that he would be using several different techniques to control fume. He was invited to freely comment as the tests progressed giving his opinions about the controls and any problems he encountered in using them, especially in the three areas listed above. The observations of the study representative who witnessed the tests are also reported.

EVALUATION OF THE AIR PURIFYING HELMET

The air purifying helmet was evaluated in the same basic way as the ventilation controls, with one notable exception. The air purifying helmet is not an exhaust control method, i.e., it does not effect reductions in worker exposures by removing contaminants from the workplace. Instead, it isolates the breathing zone of the worker from the conditions of the workplace. Thus, when evaluating effectiveness and reliability, it is the effectiveness and reliability with which the isolation is accomplished that is the subject for evaluation.

TESTING FACILITY

Building

The testing was conducted at Harnischfeger Corporation's Manufacturing Training Center Complex, located in Milwaukee, Wisconsin. The building used was a separate, small facility, which was not in use at the time. No other fume or metal dust producing processes were being operated in the building.

A schematic diagram of the building is shown in Fig. 1-6. The building measures 24 feet (7.3 m) W x 51 feet (15.5 m) L x 14.5 feet (4.4 m) H, with a volume of approximately 17,750 ft³ (503 m³). One-third of the building was used for conducting the study. Welding took place on a metal table, measuring approximately 3 x 4 ft (0.9 x 1.2 m). The building was heated by two gas-fired heaters, but to avoid disruptive crossdrafts in the work area, only the heater on the far side of the building away, from the test area, was operated during the study.

8/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

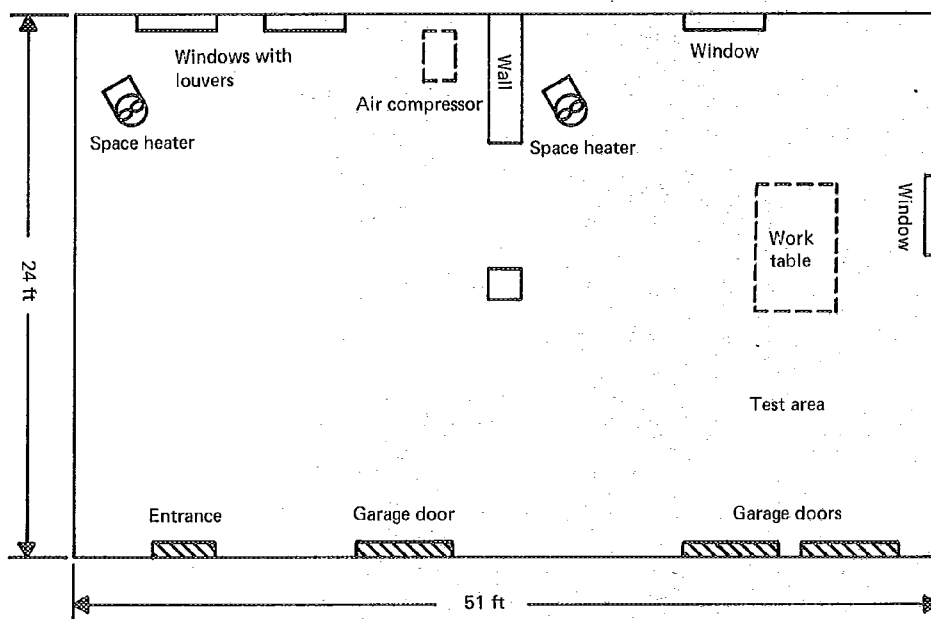


Fig. 1.6—Schematic plan view diagram of building where tests were conducted

General Ventilation and Fan Systems

Without some general ventilation, the amount of welding fume within the building would have significantly increased with time, which would, in turn, have made it more difficult to assess the effectiveness of control measures. To prevent this buildup, some general ventilation was necessary, however, care was taken to prevent disruptive crossdrafts. The general ventilation was regulated so that it could be reproduced for each test within acceptable tolerances. It consisted of a continuous exhaust of 1600 ft³/min (0.75 m³/sec) from a baffled area at roof level far enough above the work bench to prevent the creation of updrafts which could alter the conditions to which the local exhaust control methods would be subjected (Fig. 1-7). The general ventilation rate was 5.4 air changes per hour. Because it was not feasible to penetrate the roof and use a roof ventilator, a ducting section was used (back of baffled area) to exhaust air through the wall of the building. The wall exhaustor is shown from outdoors in Fig. 1-8. Just below it in the figure, the blower system is shown which was used to exhaust the high volume control devices. This blower was oversized for the application so that it could be easily modulated as necessary using a flow control damper and orifice flowmeter. The exhaustor for the two low volume methods is shown in Fig. 1-9.

SECTION 2 CONCLUSIONS

(1) Each of the ventilation controls tested substantially reduced breathing zone and general area concentrations of welding generated contaminants in both open and confined spaces.

(2) The reductions in worker exposure measured in this study represent what can be achieved when control measures are used consistently and positioned properly.

(3) Both the high volume and high velocity low volume (HVLV) ventilation controls reduced breathing zone and general area concentrations of total particulate, iron, chromium, nickel, hexavalent chromium, manganese, and fluorides in both open and confined spaces to below existing OSHA PEL's. The handheld shield exhaustor was able to meet existing OSHA PEL's in open space conditions, but the existing limit for hexavalent chromium was exceeded in confined space tests.

(4) The high volume ventilation methods reduced breathing zone concentrations of nickel in all cases to below the 15 µg/m³ limit being considered by OSHA and hexavalent chromium concentrations to levels

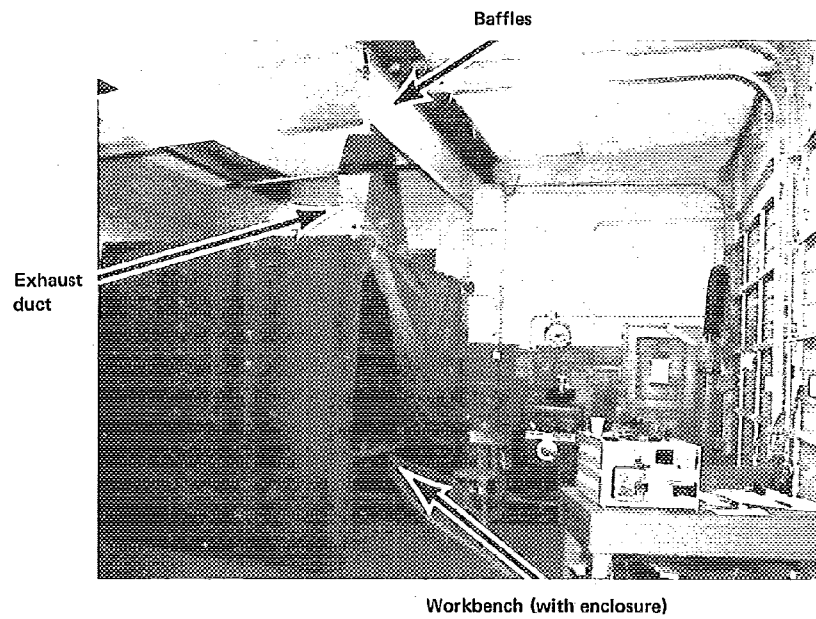


Fig. 1.7—General ventilation system

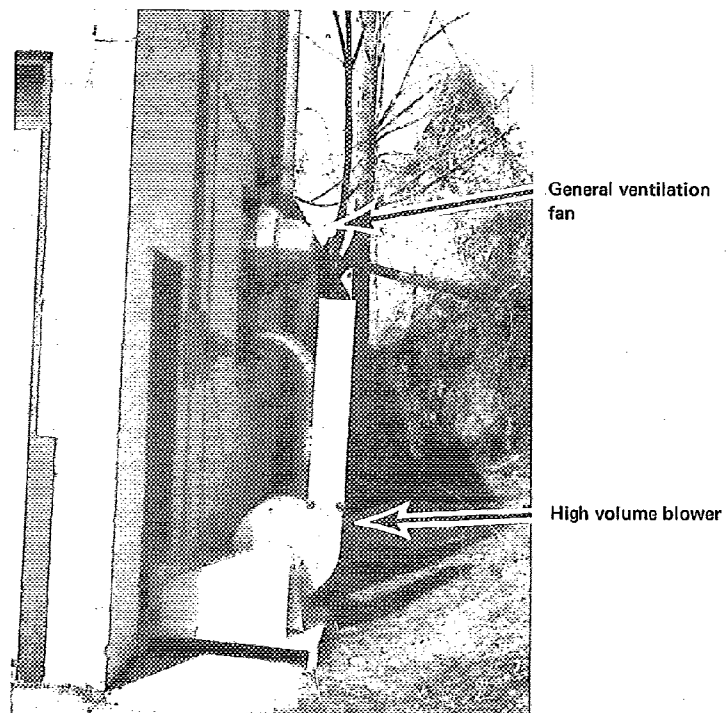


Fig. 1.8—General ventilation and high volume blowers

10/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

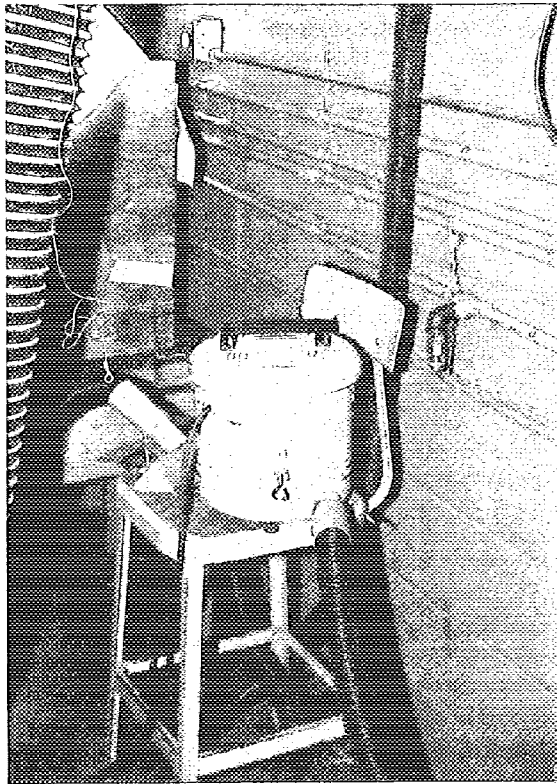


Fig. 1.9—Blower for external exhaust of high velocity low volume and handheld shield control measures

below $10 \mu\text{g}/\text{m}^3$, one of the limits being considered by OSHA. HVLV also met both of these levels in open space conditions, but on the average exceeded them in confined spaces. The handheld shield produced average breathing zone results that exceeded these new limits being considered in both open and confined space.

(5) Exposures in confined spaces were typically greater than exposures in open spaces, but not always as much greater as one would expect. This was due to the fact that the exhaust methods used to directly capture the fume also contributed to the general ventilation rate in the vicinity of the worker. This effect was especially pronounced in the case of the high volume exhauster.

(6) The air purifying helmet produced breathing zone exposures far below the existing OSHA PEL's. Nickel exposures were less than the $15 \mu\text{g}/\text{m}^3$ limit being considered, and hexavalent chromium exposures were less than $10 \mu\text{g}/\text{m}^3$, which is one of the limits being considered by OSHA.

(7) Applicability was evaluated in terms of usability, reliability, effect on the process and worker acceptance. Some of the attributes and deficiencies of the devices tested which were concluded from this evaluation are:

High Volume Exhauster

Attributes — The higher amount of exhaust used permitted some flexibility in positioning the hood.

The device was easy to use when welding in open spaces.

Deficiencies — Different devices were needed for open and confined spaces.

Some difficulty was encountered in properly positioning the exhaust in confined spaces.

The large suction opening and ductwork were susceptible to pluggage by shop rags.

High Velocity, Low Volume (HVLV)

Attributes — The relatively small size and light weight of the exhaust hose and nozzles made this method easily usable in both open and confined spaces.

A good selection of available nozzles permitted close capture in all of the positions tested.

Deficiencies — Different nozzles were needed for different tasks, requiring the worker to change nozzles during the work.

Handheld Shield

Attributes — This device was usable in both open and confined spaces with no apparent limitations.

During horizontal welding, the extractor was favorably located above the weld to receive the rising fume.

Deficiencies — Continuous awareness was necessary to assure that the extractor did not drift too far from the arc.

The device eliminated the use of one hand, which limitation the worker did not like.

Peripheral vision was obstructed by the necessity to view through a long tube.

Air Purifying Helmet

Attributes — No interferences were encountered when using this personal protective device in either open or confined spaces.

Deficiencies — When used without local exhaust capture, the performance of routine maintenance (changing filters, charging batteries) appears essential to prevent overexposure to the worker.

(8) Productivity was not affected by the use of the air purifying helmet. However, for the welding protocol used in this study, the ventilation control methods reduced productivity by about 14-17% on the average

as compared to tests where no control was used. All three ventilation controls had essentially the same impact on productivity.

(9) Selection of any of these controls measures for a specific application will require evaluation of more factors than were considered in this study, among them: cost, energy consumption, constraints of the workplace, number of welders to be controlled, and applicable air pollution codes.

(10) Linear correlations among total particulate concentrations and the various fume constituents were high under the conditions of the study, i.e., as total particulate concentrations increased, the various metal concentrations increased accordingly.

(11) Most of the hexavalent chromium generated by the shielded metal arc welding (SMAW) used in this study was of the water soluble variety. No water-insoluble hexavalent chromium was (suspected carcinogen) found in any of the samples analyzed.

(12) The data base was too small to make statistically valid comparisons between air samples taken under the welding helmet and those taken on the lapel.

SECTION 3 RECOMMENDATIONS

(1) A set of tests, similar to those conducted in this study, should be performed to determine the effectiveness and applicability of gun mounted exhausters that are commercially available for use with gas metal arc and flux cored arc welding (GMAW and FCAW). These tests should be conducted on a variety of materials, including stainless steel and aluminum. Although not necessary in the present study, measurements should be made for gaseous contaminants as well as particulate when the guns are used.

(2) A study should be undertaken, including field assessments, to identify the limiting constraints for use of a wide variety of exposure control methods and to establish selectively and design criteria on a systems basis. A systems approach could take into account such factors as number of welders, type of welding and workpiece, plant ventilation systems, energy use, capital and operating costs, climate, and potential for recirculation.

(3) Tests need to be performed to establish a statistically valid data base, comparing in-helmet and lapel sampling methods being used to determine worker exposure to welding generated particulate. These tests should be conducted in such a manner that the effect of important external variables, including fume generation rate, general air quality, welding position, helmet shape and the presence of crossdrafts on each of these measurement methods can be assessed.

SECTION 4 DISCUSSION

USEFULNESS OF CONTROLLED TEST RESULTS

The consistency of the results and the high correlation among the contaminants measured in this study attest to the merits of studying worker exposures and capture method effectiveness under controlled conditions. The team who performed this study had previously performed two other studies in industry related to welding and torch cutting fume control technology in foundries (Refs. 15 and 16). In both studies, capture methods were assessed during actual production operations. In the second of these studies, attempts were made to establish correlations among the various contaminants measured, but no such correlations were found. It is hypothesized that the primary reason for lack of correlation was that welding was performed side-by-side with other processes such as abrasive grinding, which also produced particulate containing material other than the base metal, such as sand. Cross-contamination among processes does not permit the isolation that is so necessary for establishing correlations.

A real feature of the type of evaluations performed in this study is that, besides being well-controlled, they still employ the basic essentials of a full-scale industrial welding operation. The worker was a trained welder and the workbench and workpiece and degree of confinement simulated one type of common industrial operation.

NEED FOR ADDITIONAL INDUSTRIAL ASSESSMENT

Tests in actual manufacturing operations do have their place along with controlled experimentation in establishing the effectiveness and applicability of control measures and they should be done in the present case. Field tests in a variety of industrial situations can be used to identify the limiting constraints of a particular control device and to establish selectivity and design criteria on a systems basis. A systems approach to evaluating control situations would include consideration of such factors as:

- (1) The number of welders and their proximity to each other.
- (2) The type of welding performed and the nature of the workpiece.
- (3) The ventilation systems in use in the manufacturing space.
- (4) The availability and cost of energy.
- (5) The climate.
- (6) Costs of controls and ductwork.
- (7) Air pollution codes to be met.
- (8) Potential for recirculation of cleaned exhaust air.

12/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Another difference between controlled experimentation and evaluation of existing industrial operations is that, in the latter case, it is very difficult to differentiate between deficiencies in a particular control method which may be attributed to inherent defects in the method itself as opposed to defects in applying the method. The objective of the study performed here was to install selected types of control measures and to supervise their use to assure that they were being applied properly. Important system parameters were monitored, the worker was trained in the proper use of the systems, and the operation was strictly supervised. As such, these tests probably represent a baseline defining what can be accomplished under ideal conditions. A myriad of factors could act to detract from that baseline. Chief among these factors is the improper or incomplete use of the method by the worker. There is a discipline that must be maintained by the worker which is not easy (sometimes the worker and his management don't accept the need to faithfully apply these control measures to protect the worker's health). A second leading factor contributing to ineffectiveness is lack of maintenance; third in line is probably the distribution from crossdrafts, especially from mancooler fans. It would be possible to run tests to establish the impact of each of these defects but their impacts can be widely variable, and they are for the most part preventable.

EVALUATION OF CONTROL MEASURES FOR OTHER PROCESSES

The same basic study methodology could be applied to study other forms of welding and cutting technology. A logical next step to this study, for example, could be to use an identical protocol to study gun mounted exhausters used on GMAW and FCAW equipment on stainless steel, and perhaps also aluminum.

MEASURING WELDERS' EXPOSURES

Currently, there is controversy about how the welder's exposure to air contaminants should be measured. Two basic approaches are to use: inside and outside helmet sampling. Differences in sampling inside versus outside the helmet primarily relate to the barrier which the helmet represents between the air contaminant source and the breathing zone. The inside-the-helmet method withdraws a sample on the same side of the barrier as the breathing zone; the outside-the-helmet withdraws a sample on the same side of the barrier as the contaminant source.

Limited numbers of samples comparing inside versus outside the helmet exposures were gathered in this study (Appendix D) as well as other studies (Ref. 15). The variability measured in each of these studies emphasizes the need to perform a study which will statistically define the relationships between these two sampling locations and assess the effects of important factors such as fume generation rate, general air qual-

ity, welding position, helmet shape, and presence of crossdrafts. This study could provide a basis for a better interpretation of measurements made to assess exposure during welding.

SECTION 5 TESTING PROCEDURES AND MEASUREMENT METHODS

WELDING PROCEDURES

A welding protocol was established and implemented that required welds to be made in specific positions and locations, following a set pattern and sequence. The simulated work pieces consisted of Tee shaped bars and a large circular ring that was placed on top of a workbench as shown in Fig. 5-1. The vertical barriers in the figure were installed for two reasons:

(1) To present a barrier, simulating an obstruction, around which the ventilation controls had to be moved to perform the various welding tasks involved in the sequence. This was done to evaluate the mobility of the ventilation control devices.

(2) To simulate the air baffling effect that the workpiece or other industrial obstruction may have to the direct flow of air toward the exhaust point.

The sequence of welding tasks is indicated on the plan view schematic in Fig. 5-2. Each new test always started with Step 1. All of the welds were continuous and all but Step 10 were fillet welds; Step 10 was a bead run across a flat plate. Most of the welds were horizontal, with the exception of three vertical down welds (Steps 4, 6, and 8). The sequence of tests required that the welder move frequently from one side of the vertical barriers to the other.

The Tee shaped bars measured 4 in. (10 cm) wide and high by 36 in. (91.4 cm) long. Steps 5 and 9 were performed on the same fillet piece; only the position of the piece on the table was changed. The circular weld was approximately 9.5 ft (2.9 m) in circumference. Fillet welds were placed both on the inside and outside of the circle (Steps 3 and 7).

Test Materials

All tests were conducted using 5/32 in. (3.9 mm) diameter, E308-16 electrodes and 3/8 in. (0.95 cm) type 304 plate. The compositions of the electrodes and base metal are given in Table 5-1. Welding was performed using DC (+) polarity with the machine set at approximately 130 amperes.

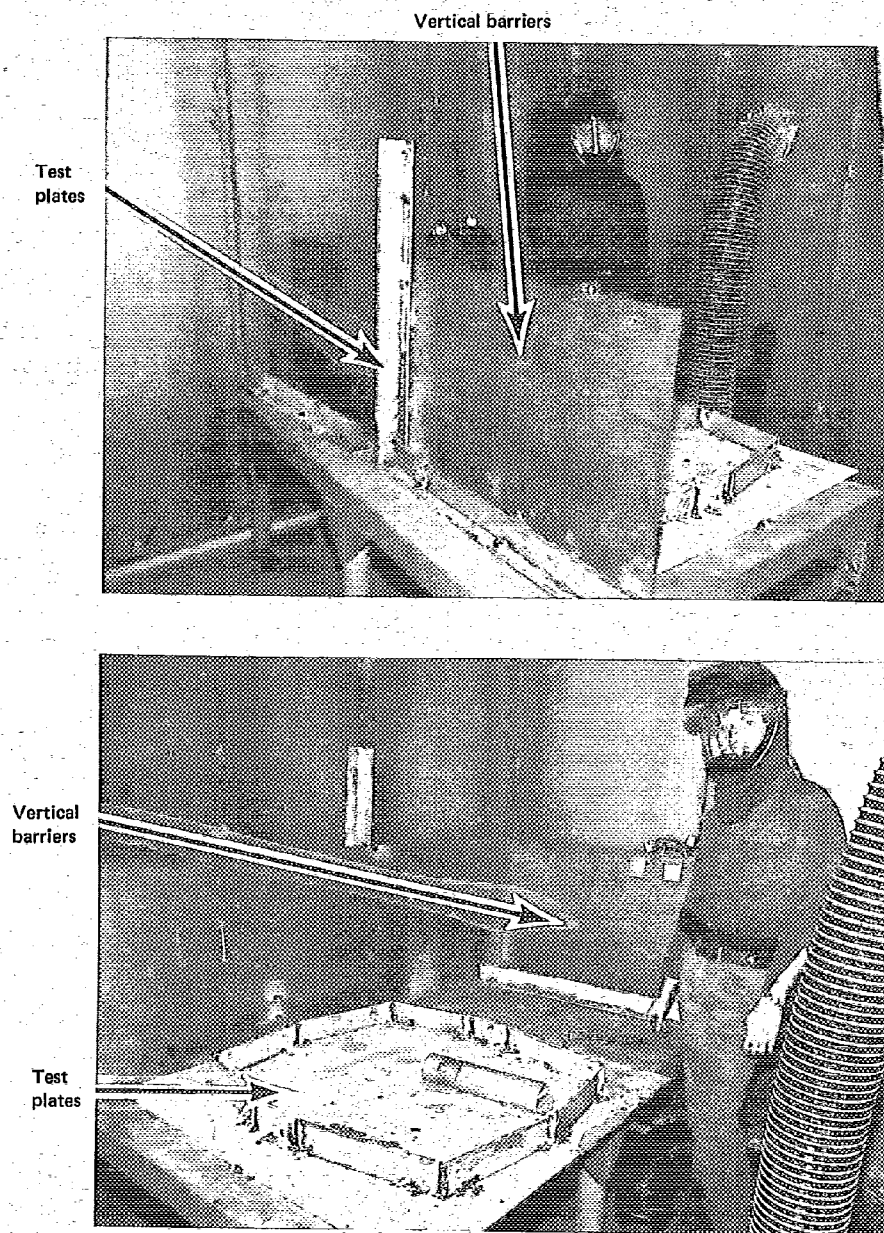


Fig. 5.1—Welding table, with test plates and vertical barriers

14/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

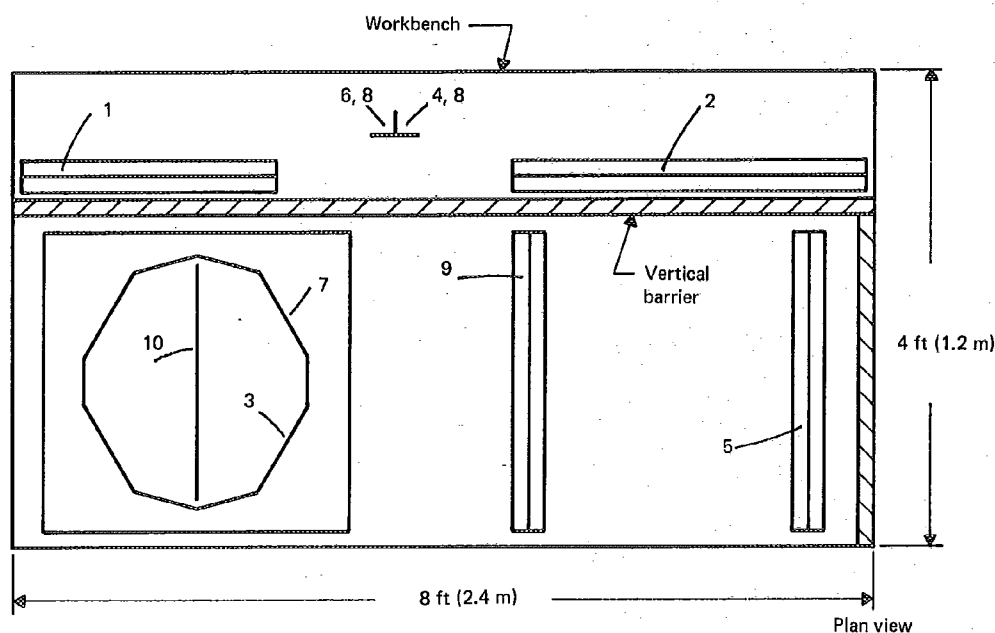


Fig. 5.2—Sequence of welding steps

Table 5-1
Electrode and base metal compositions (percentages)

	C	Mn	Ni	Cr	Cu	Co	Mo	Fe
E308-16 electrode	0.06	1.6	10.0	20.0	< 0.5	—	< 0.5	Balance
Base metal	0.05	1.77	8.70	18.21	0.15	0.07	0.18	Balance

See Appendix E for typical fume analysis.

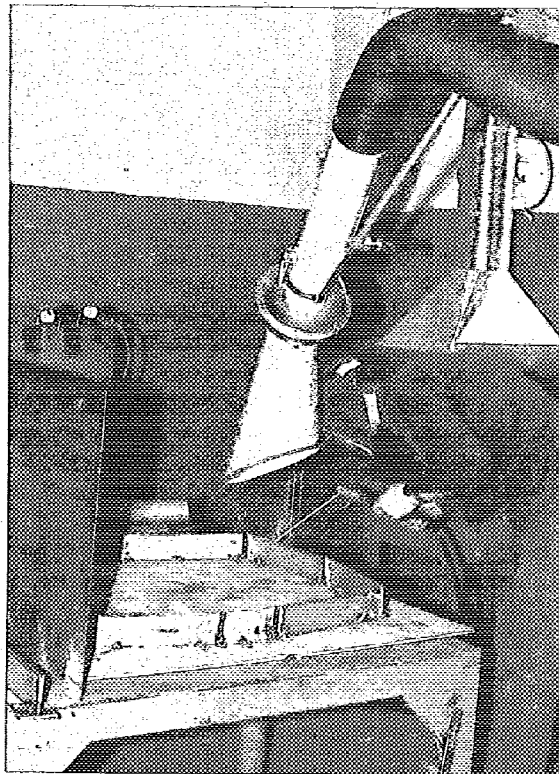
USE OF CONTROL DEVICES

The welder was given specific operating instructions for each device used, and was supervised during the tests to insure that the instructions were followed. The following summarizes the major operating guidelines for each device tested.

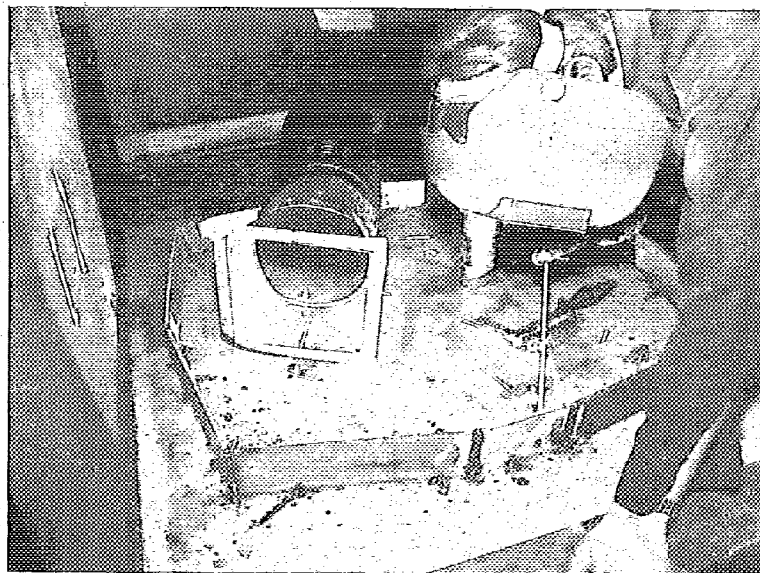
High Volume Exhauster — The ACGIH Industrial Ventilation Manual (Ref. 10) recommends various arc to intake distances based on exhaust flows ranging from 250 to 1000 ft³/min (0.11-0.47 m³/sec) for portable exhausters used in welding applications (VS-416). The recommended distance for a flow rate of 1000 ft³/min (0.47 m³/sec) is 12 in. (30.5 cm). Initial testing revealed that nearly complete capture of generated

fume occurred up to about 18 in. (45.7 cm) under the test conditions encountered in this study. This was probably due, in part, to the lack of any crossdrafts. To be conservative, however, the welder was instructed to maintain an arc to intake distance not exceeding 15 in. (38.1 cm). Photographs showing the high volume exhauster in use in both open and confined spaces appear in Fig. 5-3.

High Velocity Low Volume Extractors — The manufacturer's literature recommends that the HVLV nozzles be positioned as close to the arc as possible, within 3/4 to 2 in. (1.9 to 5.1 cm). The welder was given these same instructions, and he carefully placed the nozzles as close to the arc as possible, usually within one inch



Open space device



Confined space device

**Fig. 5.3—High-volume fume exhausters in use
(Posed picture; during tests welder wore gloves)**

16/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

(2.5 cm) but never exceeding 1.5 in. (2.5 to 3.8 cm). Visual observations indicated that this mode of operation resulted in nearly complete capture of the generated fume as shown in Fig. 5-4.

The welder used the long stick nozzle for the horizontal (Fig. 5-4) and vertical "T" welds, and the short stick and side stick for the horizontal welds made on the circular workpiece (Fig. 1-3).

The spark trap, located in the blower, was emptied before each test to prevent flow loss.

Handheld Shield Extractor — The handheld shield exhaustor was used by connecting it to the HVLV blower system. Again, due to the small volume of air exhausted, the arc to nozzle intake distance was critical. However, unlike the HVLV device, maintaining a close distance, such as 3/4 to 2 in. (1.9 to 5.1 cm), was very difficult to accomplish with the handheld device because of the nature of the device. Using the HVLV control, the worker assured himself of maintaining proper distances using the following sequence:

- (1) With the helmet up, the control was placed in proper position for welding. The welder could plainly see how much welding he could perform with the control in this position.

- (2) With the helmet down, the welder could see when a predicted length of bead was laid or that the bead was about to extend beyond the end of the suction nozzle.

Using the handheld exhaustor, the positioning method was different. Rather than making a series of position changes, the welder had to continuously remember to keep the end of the suction device close to the weld (Fig. 5-5). There was no fixed reference frame by which he could tell the device was properly placed, only his experience in using it. Therefore, as could be expected, drifting of the position of the suction nozzle was seen to occur during welding. The test supervisor thus assumed the role of indicating to the welder when the distance of the nozzle from the weld was getting excessive and fume was beginning to escape. This procedure was followed to assure that this device was also used effectively.

Air Purifying Helmet — For the air purifying helmet to be effective in protecting the welder's breathing zone, it is critical that the clear plastic face shield be kept down to maintain a seal around the worker's face and thus effectively isolate the worker's breathing zone from the outside environment. The welder was given strict instructions to keep the clear plastic shield in place at all times.

The air flow module was attached to the worker's waist with an adjustable belt (Fig. 5-6). The air flow rate was checked using a manufacturer supplied air flow gauge at the beginning and end of each test to insure that it remained within manufacturer's specifications. Filters were changed as necessary.

SIMULATION OF OPEN AND CONFINED SPACE CONDITIONS

The study requirements mandated that tests be conducted in both open and confined space conditions. Therefore, a method of simulating a confined space was developed that could be easily placed in position and removed from around the same work configuration as was used for the open space tests. This was done by constructing a metal enclosure, mounted on casters, measuring 8 ft high x 8 ft wide x 9 ft deep (2.4 x 2.4 x 2.7 m), and having a volume of 576 ft³ (15.5 m³).

The testing station with the enclosure in place is shown in Fig. 5-7. A tinted plastic curtain covered the face of the enclosure, which allowed entry and viewing from the outside. The curtain was kept closed during the tests. Auxiliary lighting was used inside the confined space as needed.

AIR SAMPLING PROGRAM

Each device was tested three times under both open and confined space conditions using a testing sequence which was randomized for each of the three sets of experiments. The experimental design for the field testing is summarized in Table 5-2.

Air samples were taken at four locations throughout the testing phase of the study and analyzed for total particulate, selected metals and fluorides:

- (1) On the worker's lapel (lapel)
- (2) Inside the welding helmet (breathing zone)
- (3) Within the work area (general area)
- (4) Inside the building near the louvered air inlets (background)

When confined space tests were run, general area samples were taken within the confined space; in open space conditions, samples were taken in the same relative position within the open area. Three replicate sets of samples were collected for each of the eight ventilation conditions that were tested (Table 5-2).

Sampling Methods

All of the air samples were collected using 37 mm filters. Air was drawn through the filters at 2 l/min by DuPont® Model P-2500 constant flow sampling pumps. Rotometer checks of the flow rates at the beginning and end of each sampling period verified that the flow varied less than +5 percent as specified by the pump manufacturers.

Filters were housed in standard 37 mm acrylic cassettes and in-helmet samples were collected by fastening an open-face 37 mm filter holder with a bracket within the helmet as shown in Fig. 5-8. In the case of the air purifying helmet, the breathing zone sample was taken under the clear plastic shield (Fig. 5-6).

Metal samples were collected on PVC membranes filters and particulate fluoride samples were collected

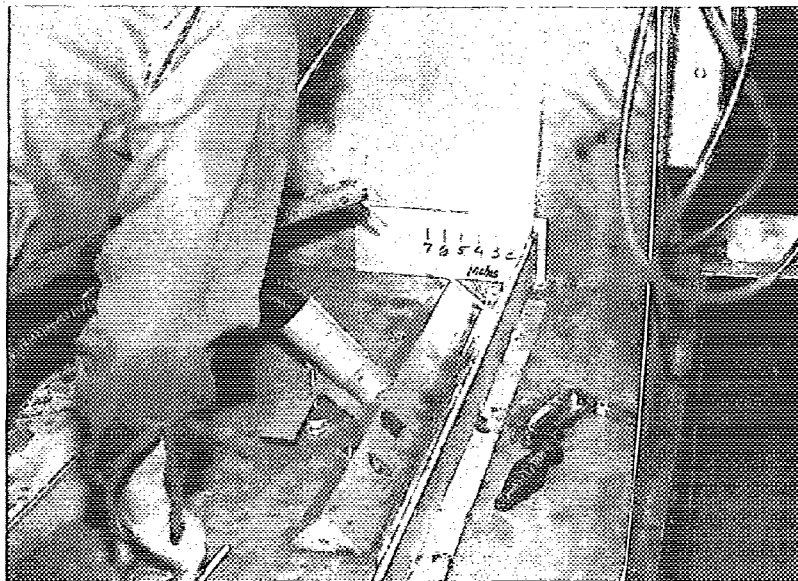


Fig. 5.4—Long stick nozzle in use
(Posed picture; during tests welder wore gloves)

on mixed cellulose ester membrane, both having a pore size of 0.8μ . All of the measurements made as part of this study are classified as time-weighted averages (TWA). The standards being considered for hexavalent chromium include ceiling values, however, there is no analytical method available for measuring them.

In-helmet Measurement — The AWS recommended method for determining worker exposure to welding generated particulate specifies that the filter cassette be placed within the helmet (ANSI/AWS F1.1-1978). Typically, one sample is collected at a time using this method. The constraints of this study required two modifications to this procedure:

(1) In order to simultaneously measure both metals and hexavalent chromium, two samples needed to be extracted from within the helmet. This resulted in a larger volume of air being withdrawn from the space between the worker's face and the helmet.

(2) Because some of the conditions tested produced potential for exposures to contaminants which may have a deleterious effect upon the worker's health such as nickel and chromium, it was necessary that the worker wear suitable respiratory protection. Disposable dust/fume/mist respirators were used because they easily fit within the confines of the welding helmet (3M Type 9920).

To determine the potential effect of these two changes on breathing zone concentrations, a short study was performed in which the method used in this study (two samples simultaneously taken under the helmet and the use of a respirator), was compared to the standard method (one sample under the helmet, no respirator). Air samples were taken during welding on mild steel under open space conditions with no local ventilation but with the general ventilation system in operation. These preliminary tests indicated that the differences in the under helmet methods differed less than 15 percent for total particulate and the metals. Due to the small variations found, in-helmet sampling using 2 filters and the respirator was used.

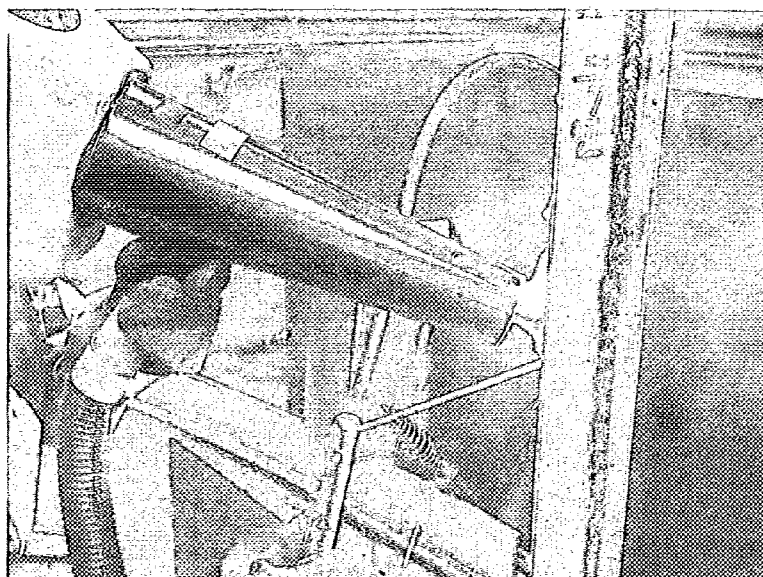
Analytical Methods

The following analytical methods were used to determine the content of selected contaminants in the samples taken:

Total Particulate — Total particulate measurements were made on each sample gathered during the field testing phase, regardless of the final analysis being performed (metals, hexavalent chromium, or fluorides). Total particulate analyses were performed gravimetrically with a Mettler type H-20 analytical balance.

Metals — Nickel (Ni), iron (Fe), manganese (Mn), and chromium (Cr) were analyzed using a method that

18/WELDING FUME CONTROL: A DEMONSTRATION PROJECT



Vertical position



Horizontal position

Fig. 5.5—Handheld shield in use

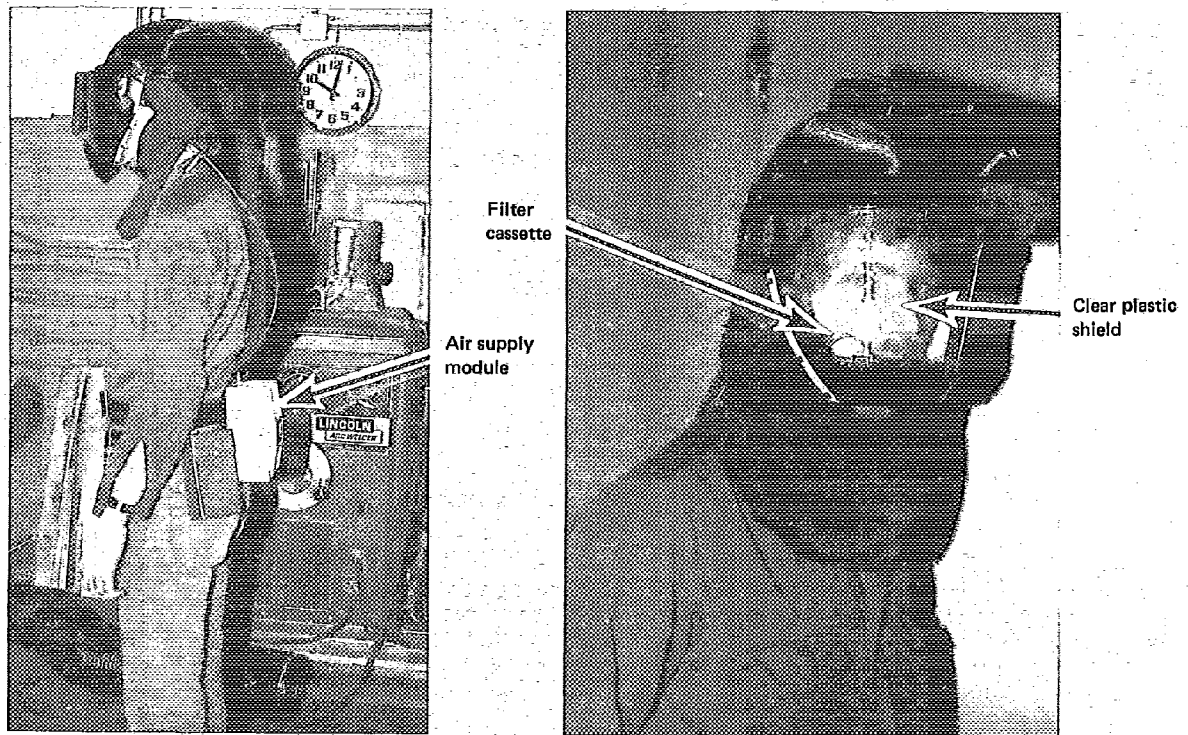


Fig. 5.6—Air purifying helmet

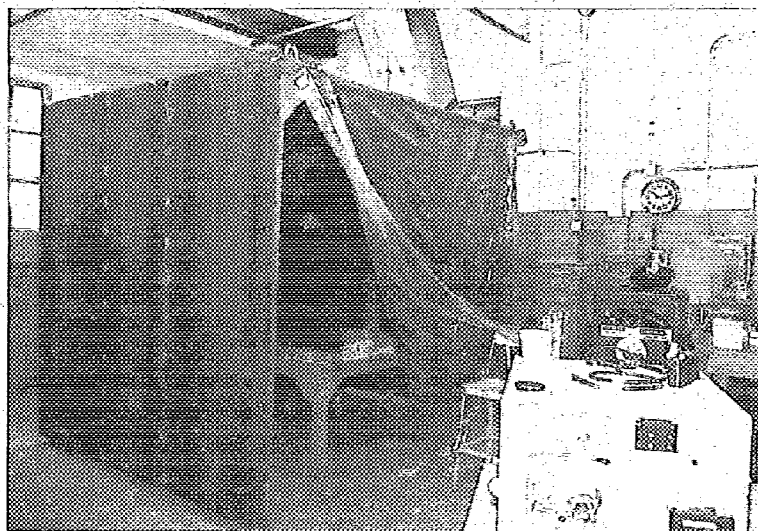


Fig. 5.7—Testing station with confined space enclosure in place
(Curtain was closed during the tests)

20/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table 5-2
Experimental design summary

Device	Test condition*	Measurement locations†	Assigned number
None	OS	L, BZ, GA, BG	1
Air purifying helmet	CS	L, BZ, GA	2
High volume extractor	OS	L, BZ, GA, BG	3
	CS	L, BZ, GA	4
High velocity, low volume	OS	BZ, GA	5
	CS	BZ, GA	6
Handheld shield	OS	BZ, GA	7
	CS	BZ, GA	8

* OS – Open space
CS – Confined space

† L – Lapel
BZ – Breathing zone
GA – General area
BG – Background

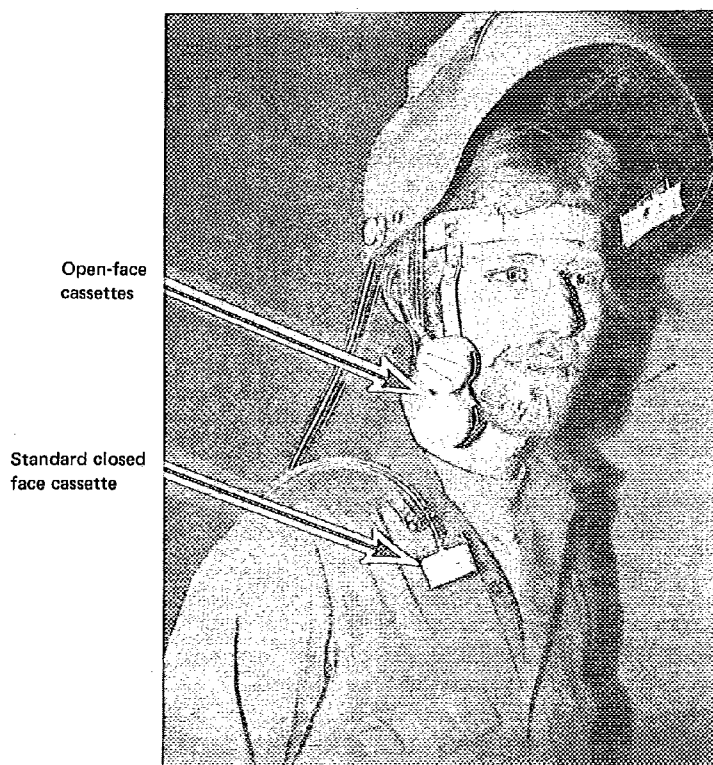


Fig. 5.8—Breathing zone air sampling methods

solubilizes the sample using sodium peroxide fusion. After fusing the sample at 500° C in a 10 ml zirconium crucible, the sample is cooled and acidified with nitric acid solution. The metal content of the solution is then determined using atomic absorption (AA).

This method was used because it recovers both nickel and chromium with satisfactory efficiency.

Hexavalent Chromium (Water Soluble and Insoluble)

— The method used was the AWS recommended method. Hexavalent chromium content of selected samples was determined by digesting the sample with a hot dilute solution of sodium hydroxide and sodium carbonate. Water soluble and insoluble fractions were separated by first washing the sample at room temperature with a 1 percent sodium carbonate solution before leaching it with the hot NaOH-Na₂CO₃ solution. Chromate content of each leach solution was determined spectrophotometrically using the diphenylcarbazide method.

Fluorides — Method 810 specified by the American Public Health Association (APHA) Intersociety Committee was used. The method employs a filter "sandwich" incorporating a membrane filter for collecting

the solid phase and an alkali-impregnated cellulose pad for collecting the gaseous phase. The membrane filter (cellulose membrane, 0.8 μ pore diameter) and collected material are made alkaline, ashed, and the fluoride content of the solution made of the melt is determined with an ion selective electrode. Gaseous fluoride is determined in an aqueous extract of the cellulose backup pad, also using an ion selective electrode.

Arc Time Measurement

Arc time was measured so that the amount of welding performed during any particular test could be measured and the effect of the devices tested on work productivity could be assessed.

Arc time was measured by two methods:

(1) A clock, tripped by a coiless relay which provided a cumulative measurement.

(2) A square wave generator that indicated the number of electrodes that had been consumed in addition to the total arc-on and arc-off times.

A schematic diagram of the measurement systems used is shown in Fig. 5-9.

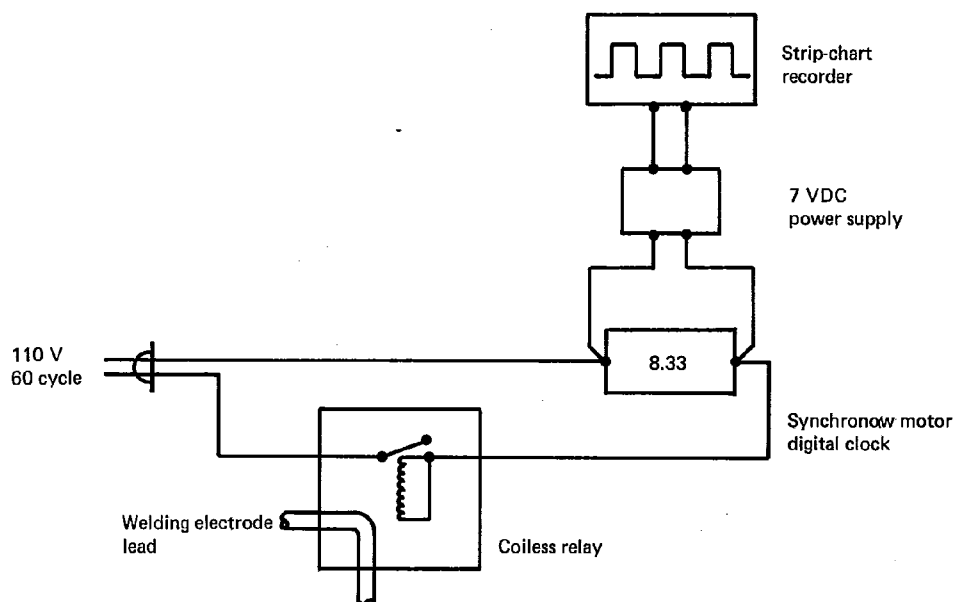


Fig. 5.9—Arc time measurement system

SECTION 6 EVALUATION OF EFFECTIVENESS

INTRODUCTION

This section presents a summary of the experimental results of the air contaminant monitoring. Both ventilation controls and the respiratory protective device are discussed, although the term "effectiveness" as applied to each is different (see Section 1, pp. 2 and 8).

The results presented in this section are based on test using commercially available devices in accordance with the manufacturers' specifications.

EXPOSURE REDUCTION FOR VENTILATION CONTROLS

Total Particulate and Metals

Use of each of the three controls studied resulted in large reductions in worker exposure to welding fume constituents (Table 6-1). Reductions were calculated by dividing the average breathing zone exposures to specific contaminants measured with the control being used by the average exposures measured under no-control conditions.

Reductions ranged from 25 percent to greater than 99 percent. Twenty-eight of the 33 measured reductions were above 70 percent. As expected, in the greatest majority of cases the exposures in confined spaces were greater than the exposures in open space conditions, but the differences were not as great as one would have expected on the basis of the no control exposure data. With no controls in use, i.e., with no local controls but with the general ventilation system operating, there was a tenfold ratio of exposures between confined and open space conditions. But using local controls the ratio ranged from 1.4:1 to 6.1:1. There was no reason to expect that the capture efficiency of the control measure changed by varying the degree of confinement. Crossdrafts could have caused efficiency changes, however, there were no significant crossdrafts during the test program (random velocities existed in the range of 10-30 ft/min [0.05-0.15 m/sec]). Based on the assumption that the capture efficiencies stayed constant for any particular control measure, the same amount of contaminants would have escaped into the general area around the welder in both open and confined spaces. However, those contaminants did not accumulate to the same extent with a capture hood in use as they did without, because the capture hood increased the general ventilation rate, i.e., caused a larger number of air turnovers per hour in the space around the welder. This observation can be borne out by comparing the results

of the Hi-Vol capture method versus both of the other lower volume methods, i.e., HVLV and handheld shield. In open space conditions, the use of the Hi-Vol exhaustor resulted in an exposure to total particulate of $174 \mu\text{g}/\text{m}^3$. Confining this operation only raised the exposure 40 percent to $238 \mu\text{g}/\text{m}^3$ on the average. On the other hand, confinement of the HVLV and handheld shield methods increased exposures to total particulate by a factor of 4.5 and 6.1, respectively. This is a trend that would be expected to have an even more drastic effect as the degree of confinement increased.

These observations can be further borne out by referring to the area concentration values presented in Fig. 6-1. Comparing open versus confined space data for the three ventilation controls (right side of graph), it can be seen that area concentrations significantly increased when the low volume methods were used in confined spaces. On the other hand, area concentrations stayed approximately equal in open and confined spaces when the Hi-Vol method was used.

These same relationships were also apparent for the other contaminants measured (see Appendix A).

Comparison to Breathing Zone Standards — The Hi Vol exhaust method met all of the existing Permissible Exposure Limits (PEL) in both open and confined spaces, as well as the limits being considered for nickel and chromium with the exception of the $1 \mu\text{g}/\text{m}^3$ standard being considered for hexavalent chromium.

When used in open spaces, the HVLV method met all of the existing standards as well as the standards being considered, again with the exception of the $1 \mu\text{g}/\text{m}^3$ standard for hexavalent chromium. In confined spaces, however, several measurements were in excess of the $15 \mu\text{g}/\text{m}^3$ standard being considered for nickel and both the 1 and $10 \mu\text{g}/\text{m}^3$ alternatives being considered for hexavalent chromium.

In open spaces, the handheld shield did not meet either of the following standards which are being considered: $15 \mu\text{g}/\text{m}^3$ for nickel and $1 \mu\text{g}/\text{m}^3$ for hexavalent chromium.

In confined spaces, the existing hexavalent chromium standard ($50 \mu\text{g}/\text{m}^3$) was exceeded in some cases with this method as well as the nickel standard being considered.

Statistical summaries of the breathing zone and area measurements for total particulate and selected metals are presented in Appendix B.

Correlations Among Fume Constituents — Linear correlations were performed to determine how well the levels of the different fume constituents correlated to total particulate and to each other. This was done by fitting straight lines to the data using the method of least squares. Correlations were calculated and plotted for breathing zone data only, as well as for both breathing zone and area data combined. The results of these correlations are presented in Appendix C.

Table 6-1
Average breathing zone exposures and reductions achieved

Average breathing zone concentration, $\mu\text{g}/\text{m}^3$													
Control type	Total particulate		Iron		Total chromium		Nickel		Hexavalent chromium*		Manganese		Condition
	OS†	CS‡	OS	CS	OS	CS	OS	CS	OS	CS	OS	CS	
High volume (Hi-Vol)	174	238	16.1	14.9	2.5	2.5	5.0	7.0	1.6	1.3	2.5	2.0	
Percent reduction %	95	99	86	> 99	92	> 99	55	93	96	> 99	81	> 99	
High velocity low volume (HVLV)	384	1,733	27.8	56.2	9.9	27.7	5.5	11.0	1.5	5.4	7.4	21.1	
Percent reduction %	90	95	77	95	70	96	50	89	97	> 99	44	97	
Handheld shield	912	5,562	25.7	192.3	10.0	124.2	8.3	20.3	10.0	56.1	7.5	117.5	
Percent reduction %	76	83	78	82	70	82	25	80	78	94	44	82	
No Control	3,757	33,335	119.1	1068.0	33.2	699.0	11.0	101.0	45.0	904.0	13.2	651.0	

* - Only the water soluble variety was found.

† - OS - open space conditions.

‡ - CS - confined space conditions.

24/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

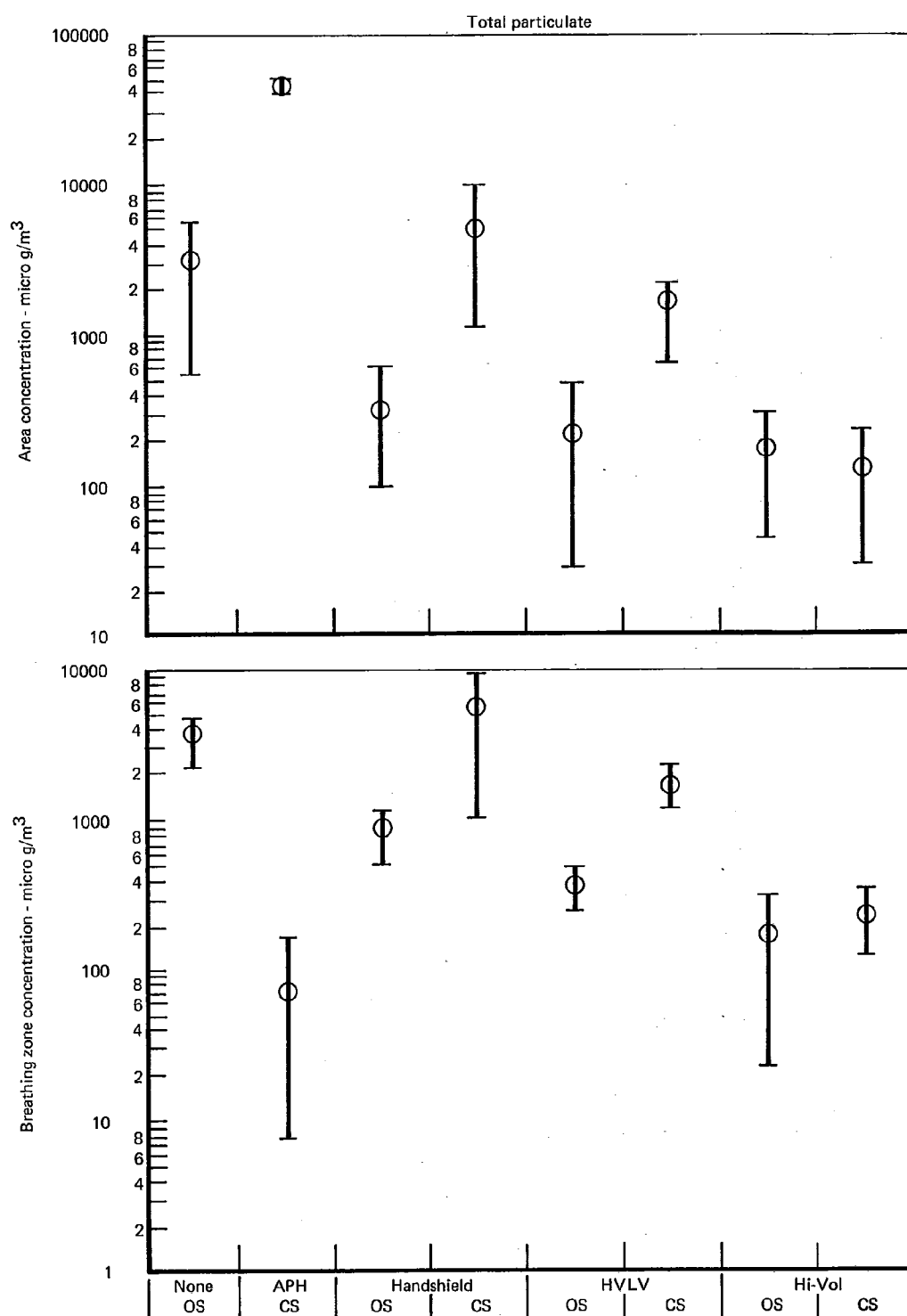


Fig. 6.1—Total dust - breathing zone and area concentration averages and ranges

The correlation coefficients were quite high, all above 0.93, indicating strong linear relationships between each of the metals and total dust, as well as among the different constituents.

Fluorides

Particulate fluoride measurements were all below 60 $\mu\text{g}/\text{m}^3$, well below the 2500 $\mu\text{g}/\text{m}^3$ PEL. Gaseous fluoride measurements were all below 3 $\mu\text{g}/\text{m}^3$.

PROTECTION FACTOR FOR AIR PURIFYING HELMET

In confined spaces, the average exposures under the helmet were less than the average exposures measured without this helmet under any conditions in either open or confined spaces (Fig. 6-1 and Appendix A).

Protection factors, i.e., ratios of exposure outside versus inside the air purifying helmet, were calculated from the air sampling data and are presented in Table 6-2. Protection factors varied among the fume constituents and ranged from approximately 100-700. These differences may be attributed to the low exposures measured under the helmet. Small deviations in any of the fume constituents measured under the helmet would result in significant changes in the calculated protection factors. The primary conclusion to be drawn here is that the protection factors were very large, and exposures inside the helmet were always less than 1 percent of the concentrations that existed outside the helmet.

Table 6-2
Measurement results summary for the air purifying helmet

Contaminant	Average concentration $\pm$, $\mu\text{g}/\text{m}^3$		Protection factor*
	Breathing zone	Lapel	
Total particulate	7.7	33,300	432
Iron	6.0	1,068	178
Total chromium	1.5	699	466
Nickel	< 1.0	101	100
Hexavalent chromium	< 1.3†	904	> 695
Manganese	1.0	650	650

† — Measurement lower detectable limit.

* — The protection factor is defined as the ratio of the lapel measurement to the in-helmet measurement.

SECTION 7 EVALUATION OF APPLICABILITY

In this section, the evaluation of the applicability of the ventilation control measures and the air purifying helmet are presented. The criteria used in the evaluation include usability, reliability, effect on the process, and worker acceptance. Statements and descriptions of each of these evaluation factors are presented in Section 1.

It should be noted that the evaluation which is discussed here is based on measurements and observations made during this study. It is recognized that other welding situations can and do occur which could place additional constraints on the applicability of a particular control measure. These constraints are not described in this section, but are briefly discussed in the next section.

USABILITY

High Volume Exhauster

This capture method exhibited substantial flexibility in positioning because of the high volume of air used.

Positioning was found to be easy to accomplish when welding in open spaces.

Different devices, however, were needed for open and confined spaces. The retractable arms and swivel joints which permitted the hood to be placed in a position and remain there were only usable in open areas. In confined spaces, only the flexible duct and intake hood could be used. In some cases, trouble was experienced in positioning the control in confined spaces. The weight of the hose sometimes caused the exhaust opening to swivel on its magnetic attachment, requiring readjustment (Fig. 7-1).

High Velocity Low Volume

The relatively small size and light weight of the exhaust hose nozzles made the HVLV easily usable in both open and confined space conditions. There was a good selection of nozzles available having various shapes for use in different geometric positions, allowing fume to be extracted close to the weld in all conditions tested.

Handheld Shield Exhausts

This device was used in both open and confined spaces with no apparent restrictions. The relatively small size and light weight allowed the shield to be used in almost any configuration.

Air Purifying Helmet

No interferences were encountered when using the air purifying helmet in either open or confined spaces.

RELIABILITY

High Volume Exhauster

The effective use of the high volume exhaust required that the worker faithfully reposition the intake to be within about 15 in. (76 cm) from the arc. This required that he be constantly aware of how much welding could be done before position changes were necessary. With careful instruction and supervision, the worker experienced no particular difficulties in accomplishing the necessary position changes, with the exception of the enclosed space conditions where the size and weight of the hose sometimes presented some problems in maintaining the position of the hood. The hood tended to swivel on its magnet.

One system failure did occur during the testing. A shop rag entered the intake and caused a partial duct blockage, resulting in a substantial reduction in air flow. A wire cross member installed in the duct above the intake prevented the rag from reaching the fan.

High Velocity Low Volume

The effective use of HVLV also required that the worker faithfully reposition the intake, this time to be within 3/4 to 2 in. (1.9 to 5.1 cm) from the arc. And again, with careful instruction and supervision, the worker experienced no difficulty in accomplishing the necessary position changes. The sensitivity of the method to position is shown in Fig. 7-2.

Because the nozzle to arc distance is so short, three different nozzles were required to perform the welding protocol followed in this study. This required that the worker use the proper nozzle for the specific weld being performed, and switch among these nozzles as necessary.

Handheld Shield

The basic design of the handheld shield insures that the exhaust is used by incorporating the viewing glass and face shield into the fume extraction nozzle. Depending on whether the welding was horizontal or vertical, the extraction nozzle was either placed on top of or to the side of the weld (Fig. 7-3). The nozzle did not have to be as close to the weld when it was located directly above it because capture was enhanced by the thermal draft which directed the fume into the nozzle. The capture hood was effective up to 5 in. (13 cm) or more above the weld (Fig. 7-3A), whereas, effective capture from the side required that the nozzle be within about 2 in. (5 cm) from the weld (Fig. 7-3B).

Although the worker was forced to use the extractor in order to use his welding viewing shield, this fact alone did not automatically guarantee that the nozzle was maintained within the required distance for effective capture.

Figure 7-4 shows the importance of close access to proper use of the control measure. In Fig. 7-4A, the

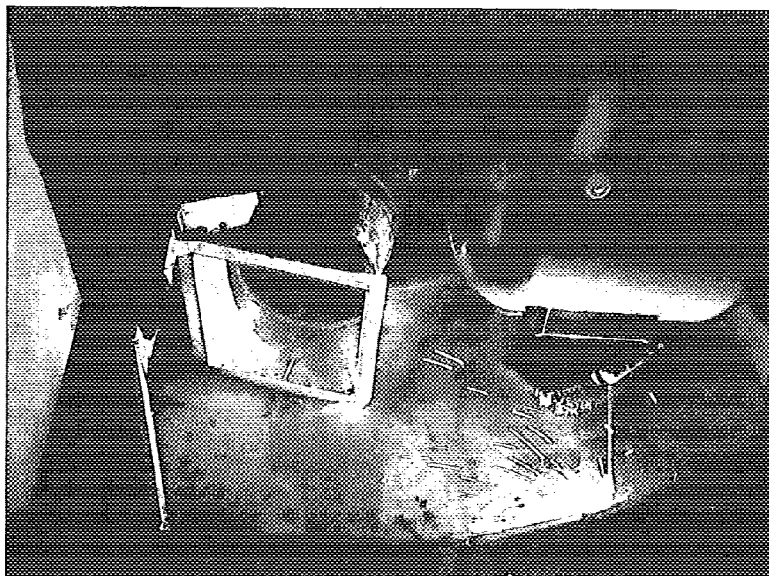


Fig. 7.1—The weight of the flexible hose had an effect on the direction of the exhaust opening in confined spaces (HI-VOL) method)

worker is not restricted from gaining close enough access to use the method properly. Figure 7-4B is a posed picture to show what would happen if obstructions prevented close access. In this case, the worker may be close enough to do the welding, but he is not close enough to use the extraction hood.

Even in cases where the hood was initially placed close enough to the welding to be effective, it was seen to drift back and forth as the welding proceeded. All of the above observations emphasize the need for the worker to be well versed in the effective use of this method and continuously aware of the need to position the extractor properly.

Air Purifying Helmet

This device required very little worker involvement for it to be used effectively. The only requirement for worker interaction was keeping the clear plastic shield in place at all times.

The air filtering unit required routine maintenance to ensure that it operated properly. The battery pack had to be charged and the HEPA filter changed regularly to ensure that the proper amount of air was delivered to the helmet. The replacement schedule for the HEPA filters was found to be a function of the particulate concentrations in the general area. Under confined space conditions (total particulate concentrations of about 30 to 50 mg/m³), the filter life was determined to be about 16 hours. The batteries required recharging

about every 8 hours of use, as recommended by the manufacturer.

The faithful performance of routine maintenance was essential to prevent overexposures because the device was used in the absence of local exhaust capture of the welding fume.

EFFECT ON PROCESS

None of the devices tested produced any noticeable adverse effects on the quality of the welding being done or unusual constraints on the welding procedure. The primary effect on the process was on productivity.

IMPACT ON PRODUCTIVITY

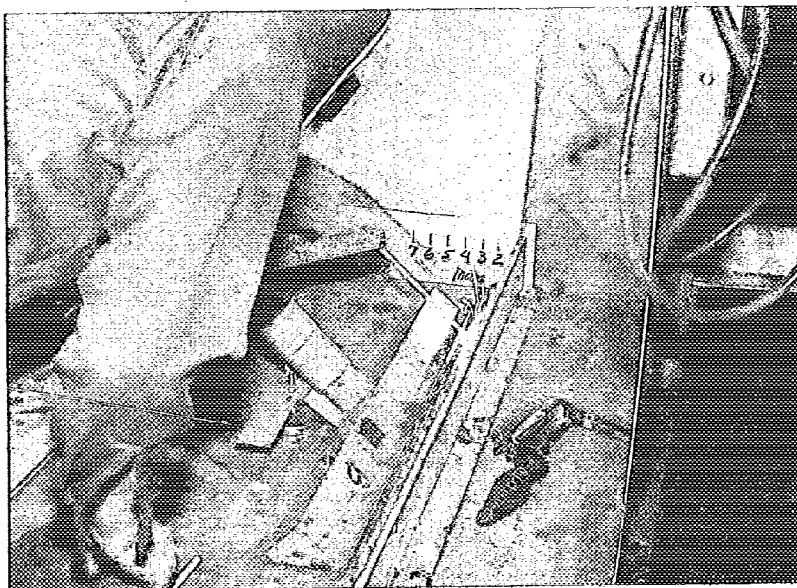
The impact that each control had on worker productivity was measured in two ways, which are summarized below:

Method 1 — Percent arc time of total work time. This was calculated by measuring the cumulative total arc time for each test and dividing by the total test time, excluding breaks and lunch periods.

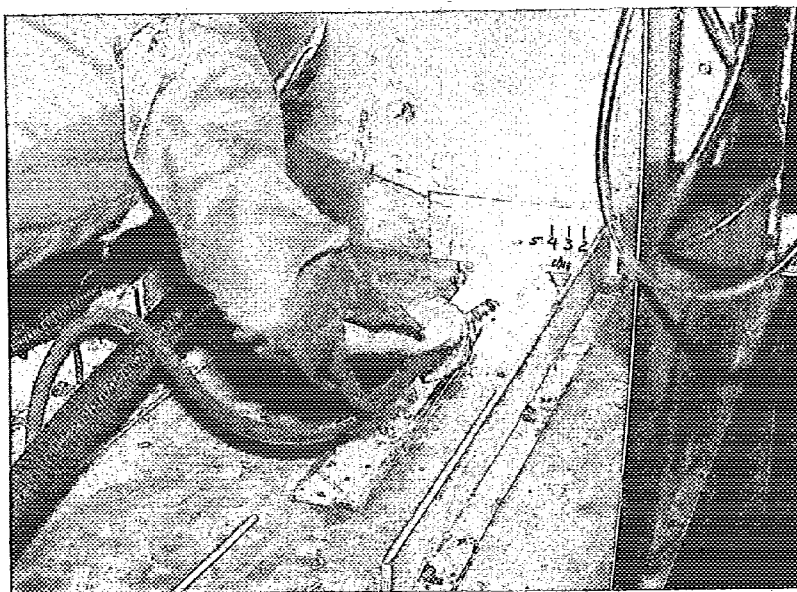
Method 2 — Number of electrodes burned per minute of work time. This was determined by counting the number of electrodes consumed and dividing that number by the total test time, excluding breaks and lunch periods.

The second method was used because any variability caused by changes in the amount of metal deposited is accounted for by increases in the electrode count.

28/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

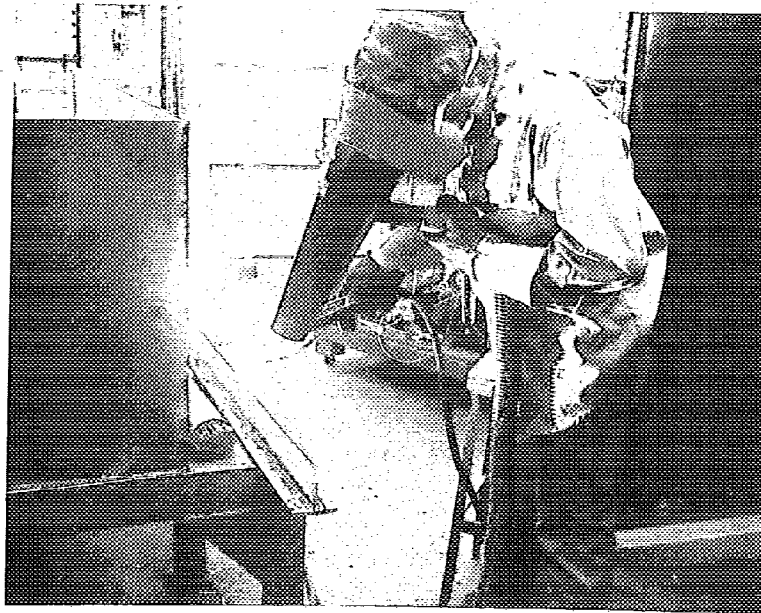


Effective capture with the nozzle positioned within the recommended $3/4$ - 2 in. (1.9 - 5.1 cm) distance of the arc.



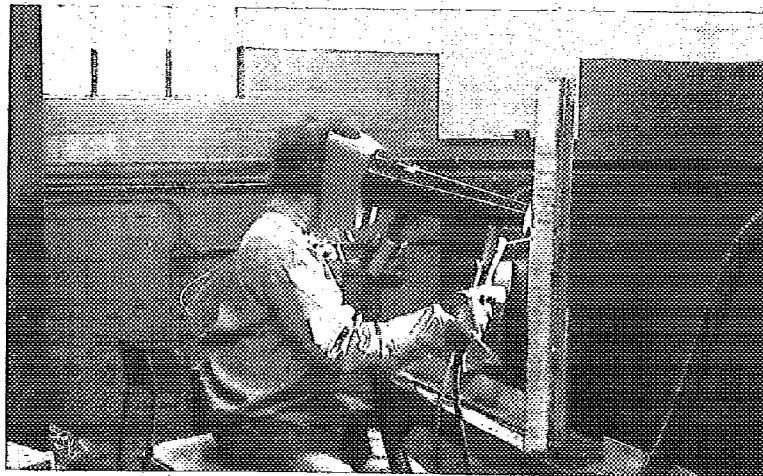
Ineffective capture with the nozzle positioned at about 4 in. (10.2 cm) distance from the arc (not allowed during testing program).

**Fig. 7.2—The effect of improper nozzle positioning on the effectiveness of HVLV
(Posed picture; during tests welder wore gloves)**



Photograph A

Horizontal welding with the nozzle positioned above the arc at approximately 6 in. (12.7 cm).

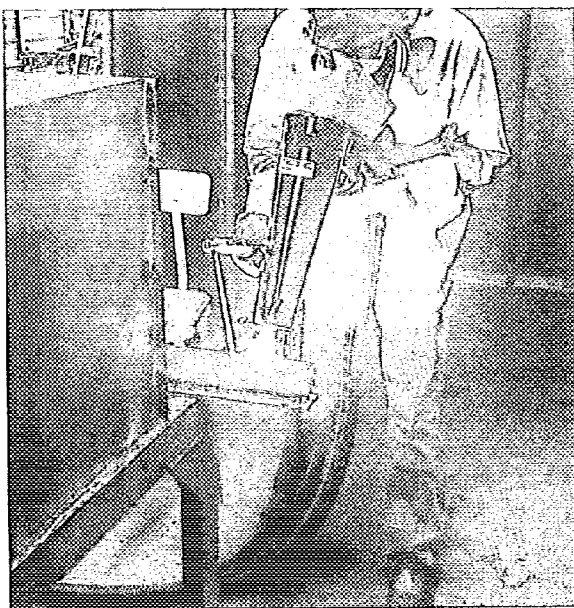


Photograph B

Vertical welding with the nozzle positioned to the side of the arc.

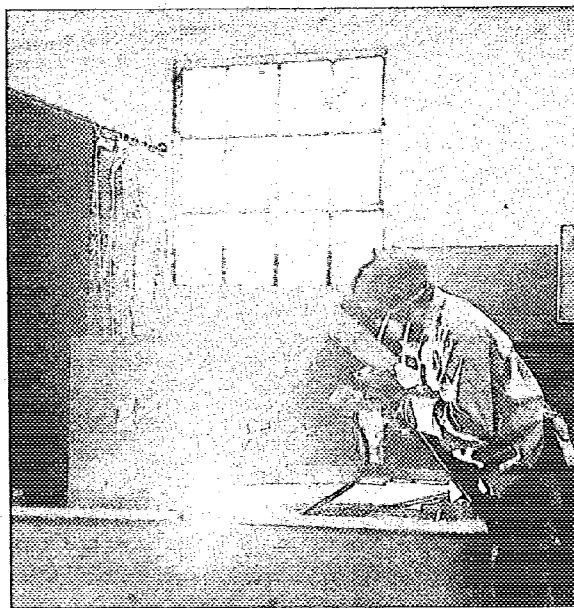
Fig. 7.3—Effect of welding position on arc to nozzle distance needed for effective fume capture using the handheld shield

30/WELDING FUME CONTROL: A DEMONSTRATION PROJECT



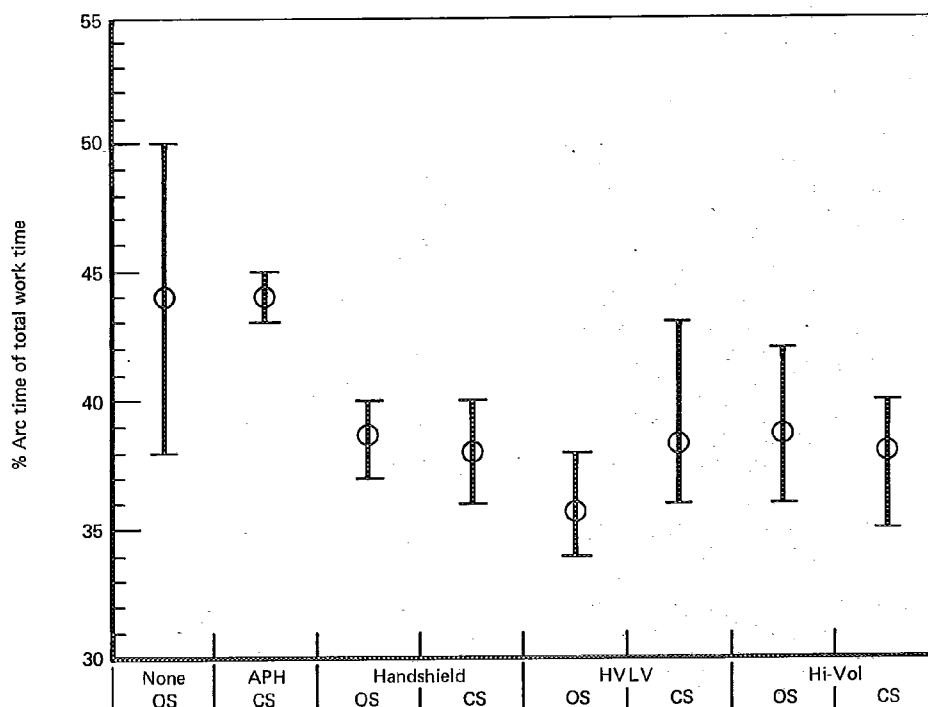
Photograph A

Handheld shield properly positioned.



Photograph B

Handheld shield improperly positioned (not allowed during test program).

Fig. 7.4—The effect of positioning on the performance of the handheld shield exhauster**Fig. 7.5—Work study measurement results - Method 1 arc time basis
(work time excludes lunch and breaks)**

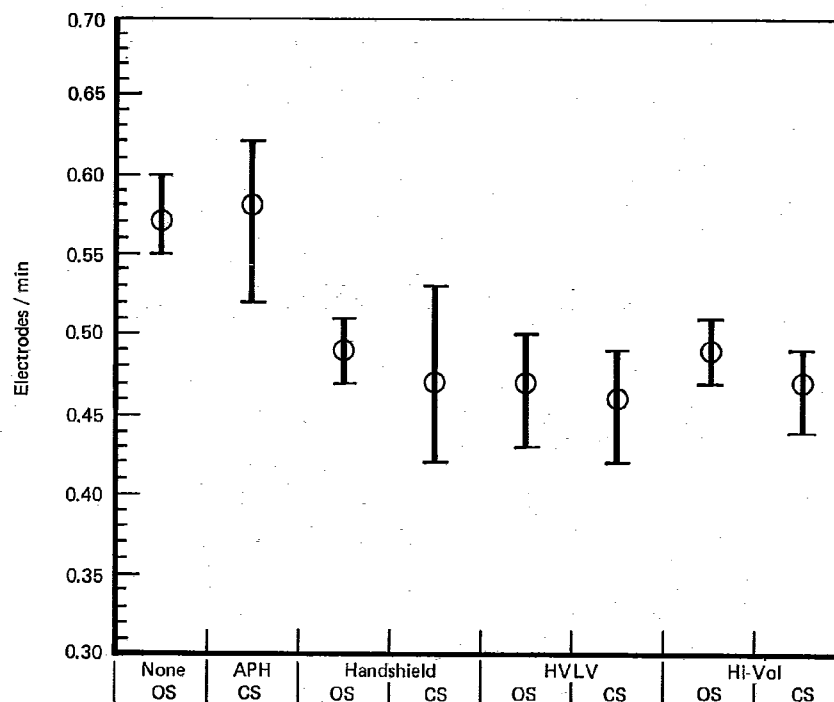


Fig. 7.6—Work study measurement results - Method 2 electrode count basis
(work time excludes lunch and breaks)

The results of method 1 (Arc time) measurements are presented in Fig. 7-5 and method 2 (Electrode count) in Fig. 7-6. Method 1 results indicate an average arc time of about 44 percent of total work time for the two conditions that did not require worker interaction to operate and reposition a control (the air purifying helmet and no-control conditions) and an average ratio of about 38 percent of total work time when the ventilation controls were used. This represents a 14 percent reduction in arc time under conditions where worker interaction is required to operate the controls. This reduction in arc time percentage between either the no-control (NONE) or the air purifying helmet, and the ventilation controls are statistically significant (F Test, $\alpha = 0.05$) but the differences among the ventilation controls are not significant.

The second type of measurements, in terms of electrodes/min., indicate approximately the same results; on the average, a 17 percent decrease in the number of electrodes consumed per minute when the ventilation controls were used.

WORKER ACCEPTANCE

The handheld shield was the only device tested that was not accepted by the worker because:

(1) It required that the welder hold the electrode holder with one hand whereas he often preferred to use two hands.

(2) It obstructed peripheral vision because the viewing of the welding was through a long tube.

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Appendix A: Breathing Zone and Area Concentration Averages and Ranges for Selected Fume Constituents

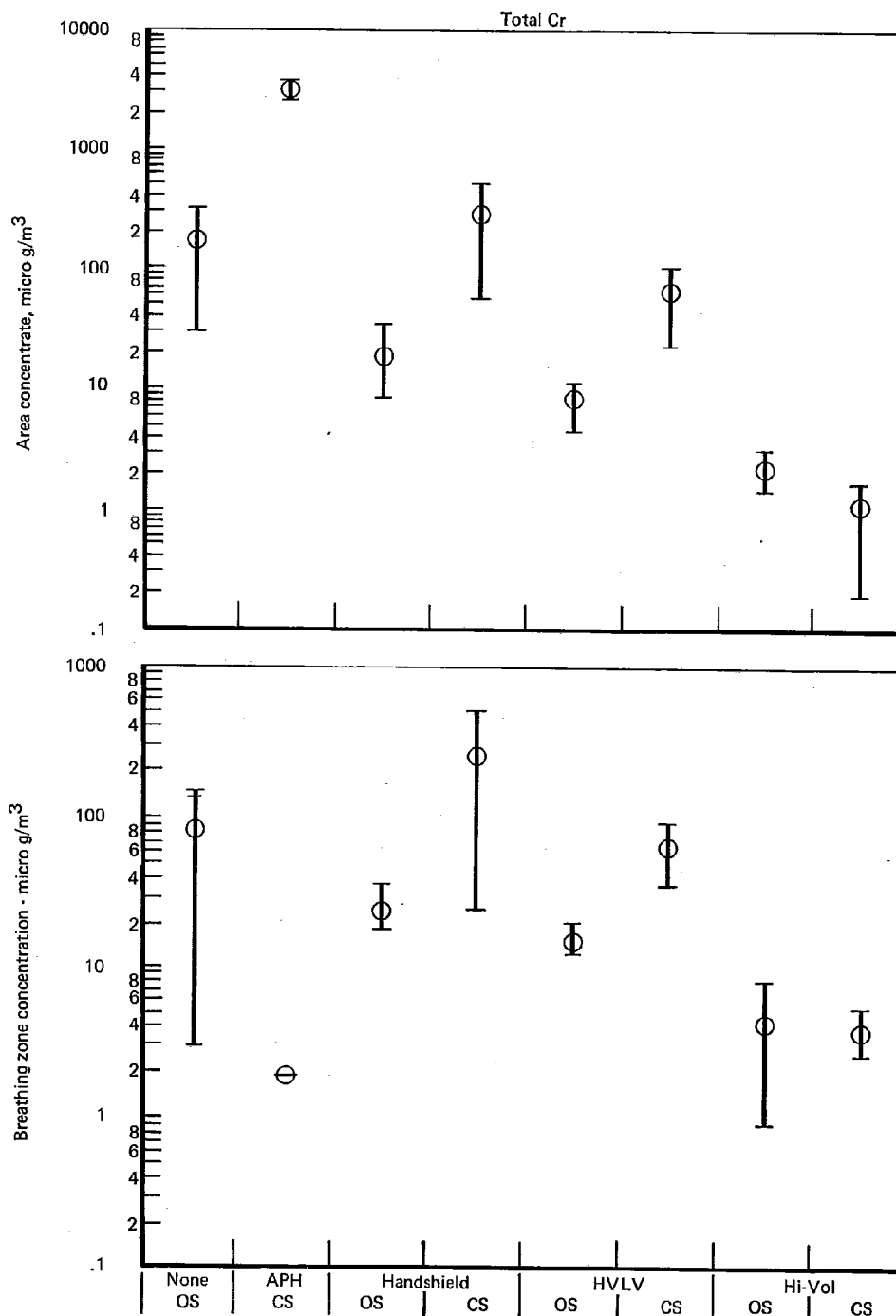


Fig. A.1—Total chromium breathing zone and area concentration averages and ranges

34/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

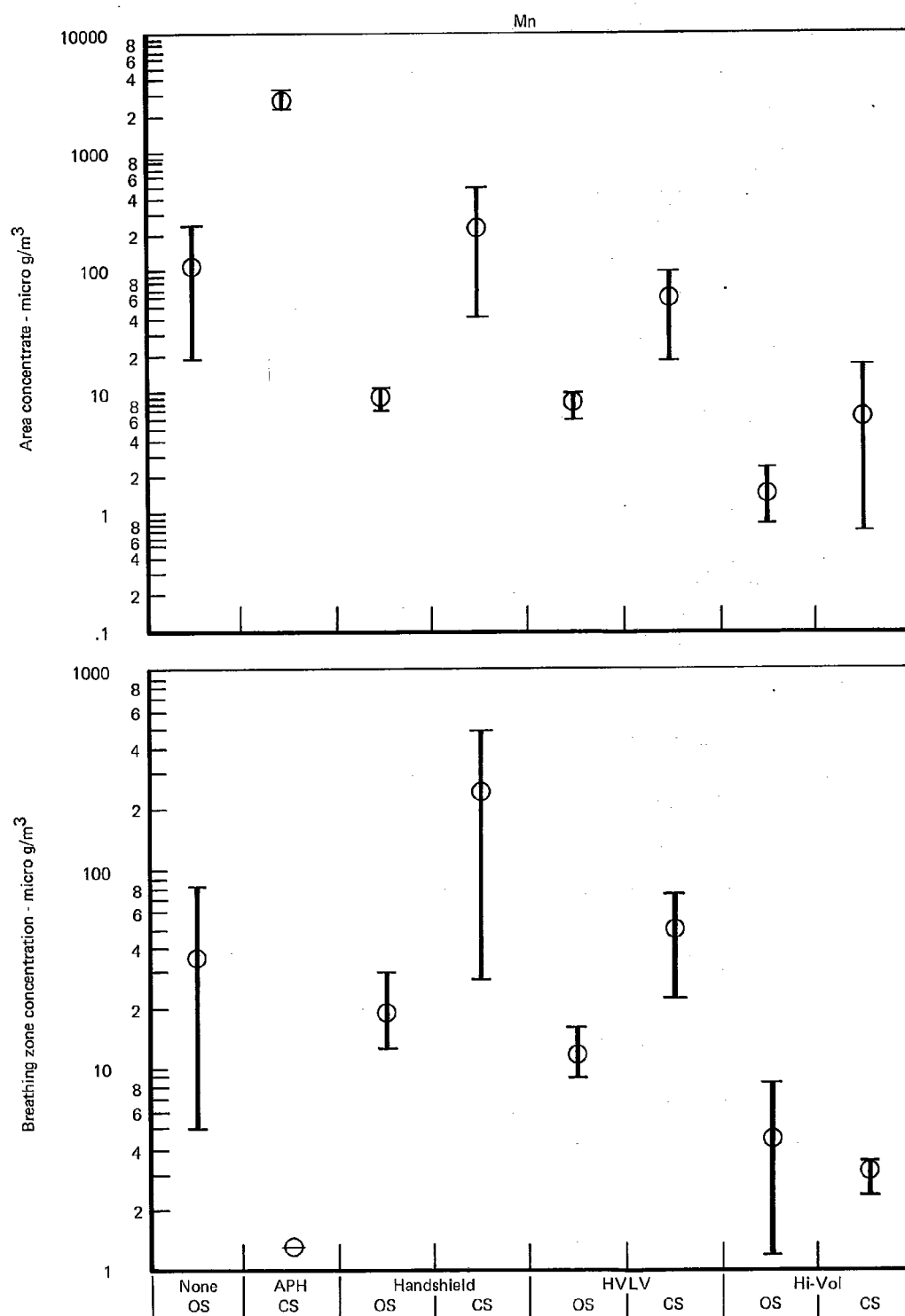


Fig. A.2—Manganese - breathing zone and area concentration averages and ranges

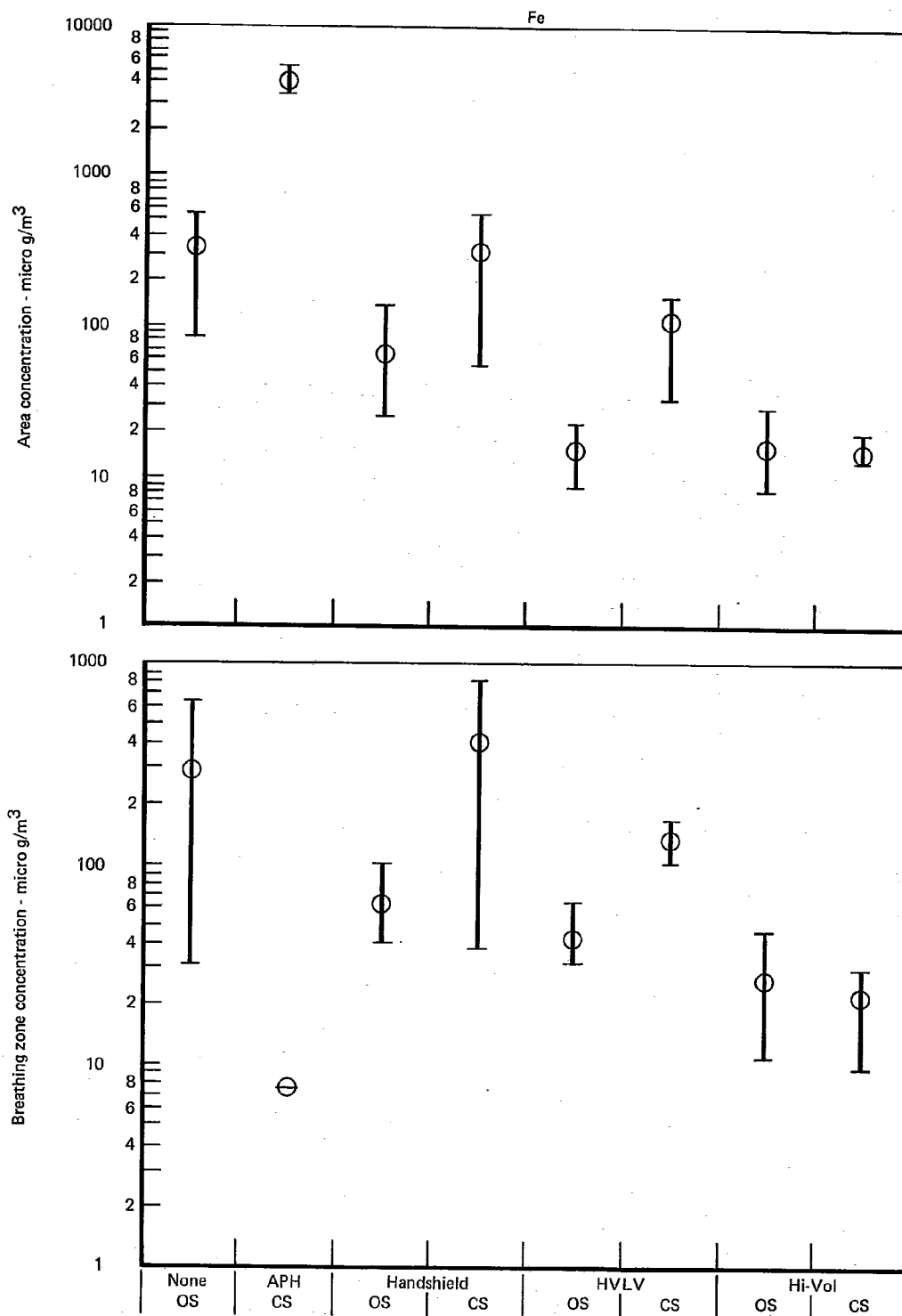


Fig. A.3—Iron - breathing zone and area concentration averages and ranges

36/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

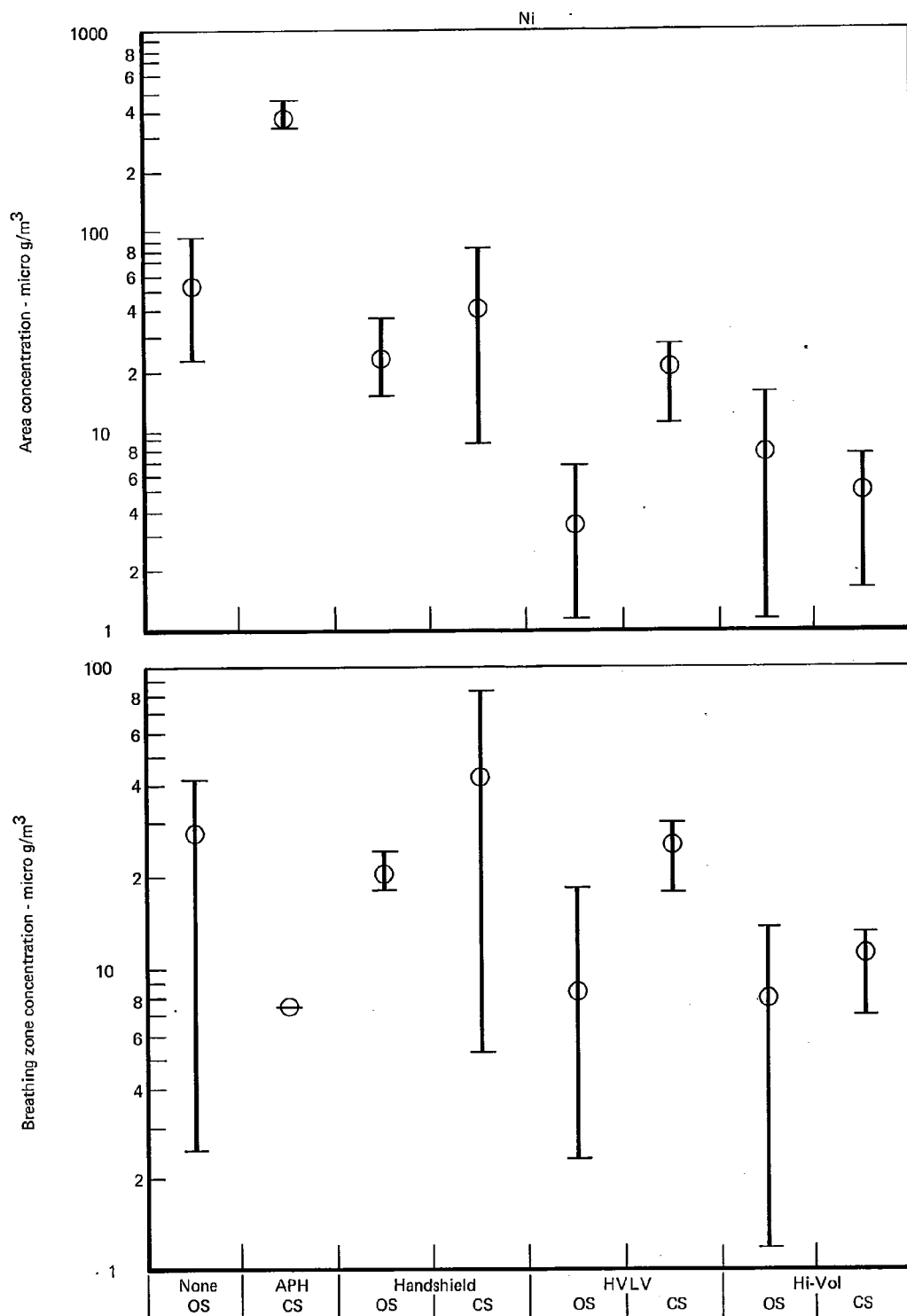


Fig. A.4—Nickel - breathing zone and area concentration averages and ranges

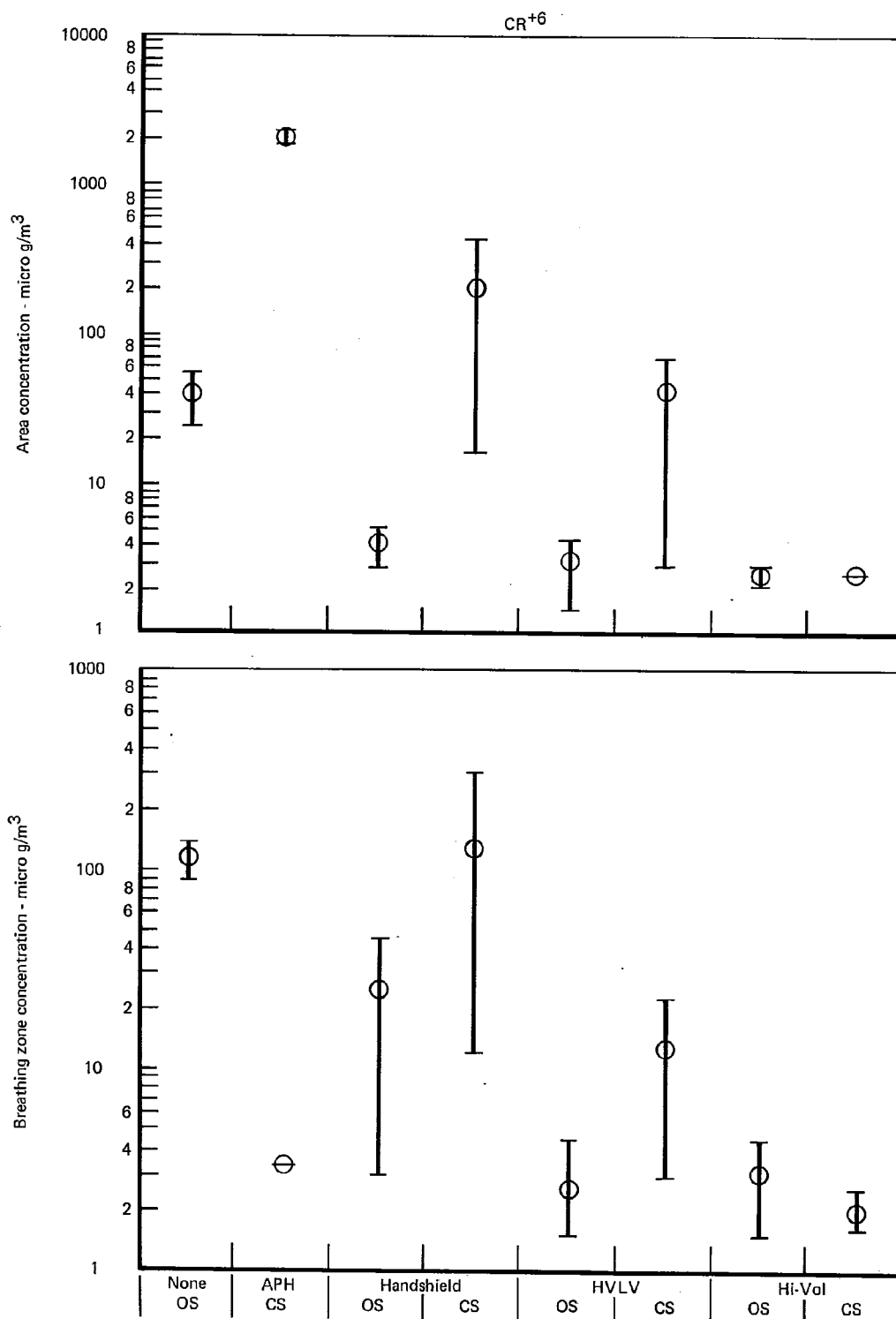
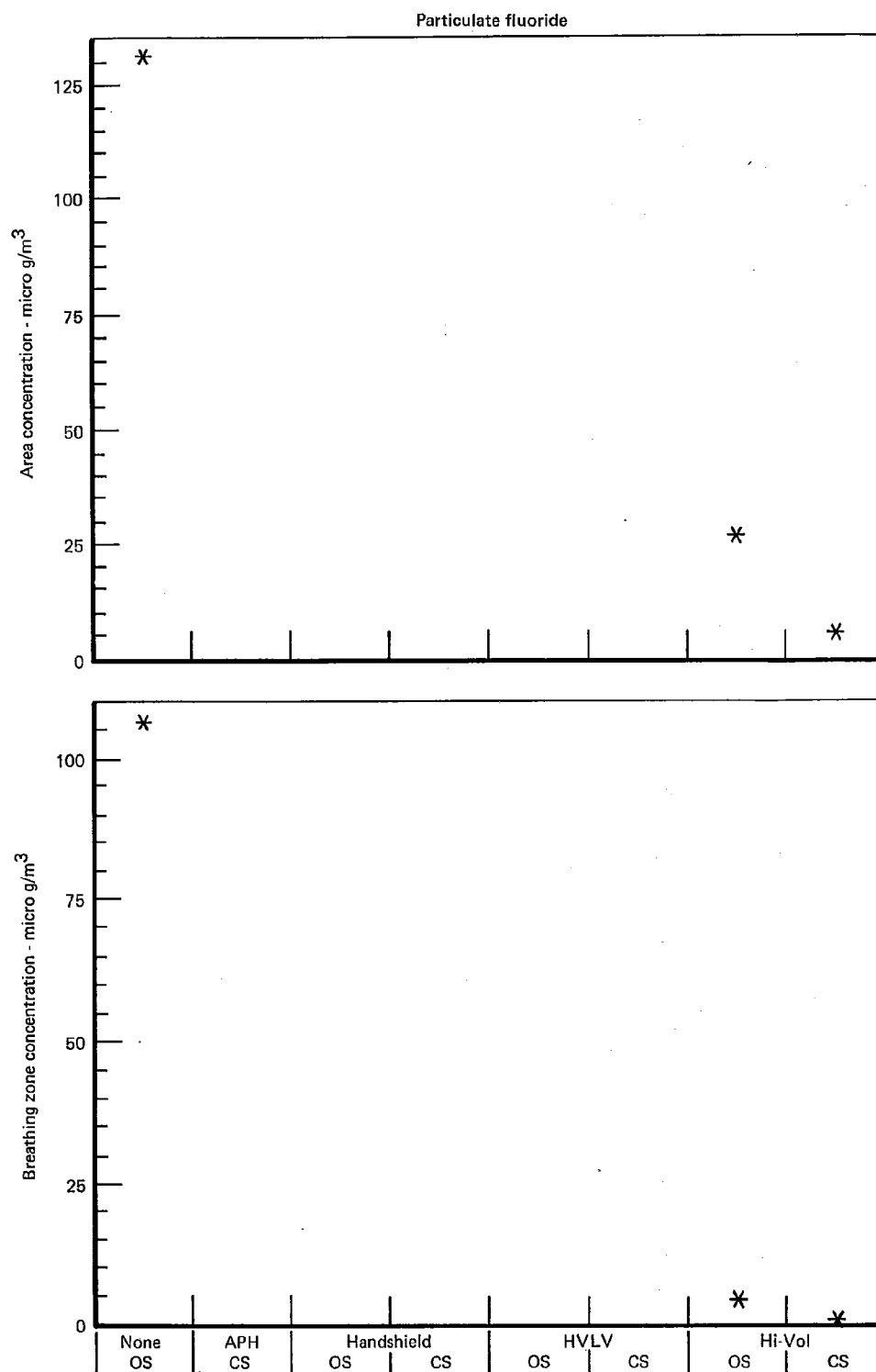


Fig. A.5—Hexavalent chromium - breathing zone and area concentration averages and ranges
 (Note: All of the hexavalent chromium measured was of the water-soluble variety)

38/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

**Fig. A.6—Particulate fluoride - breathing zone and area concentration measurements**

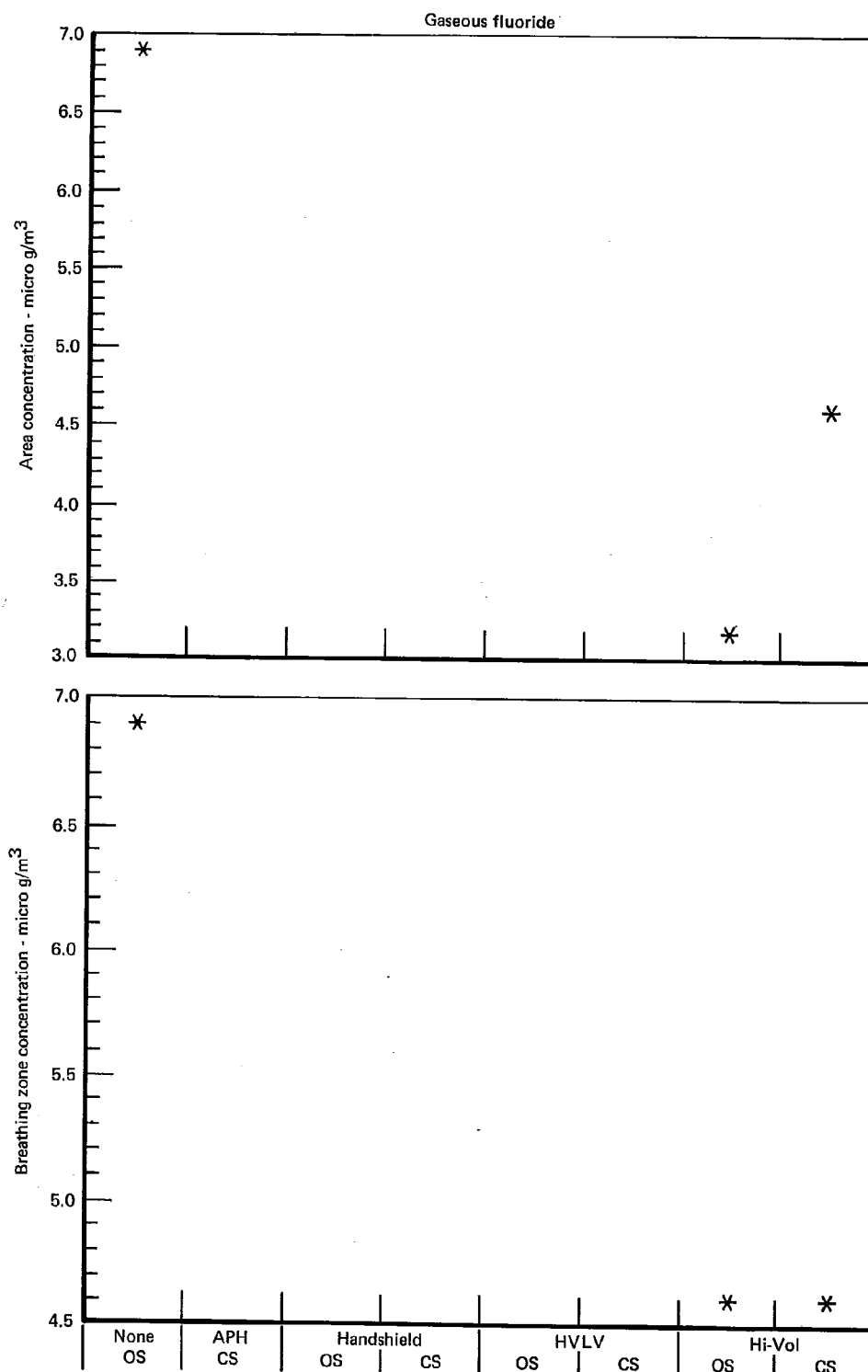


Fig. A.7—Gaseous fluorides - breathing zone and area concentration measurements

Appendix B: Statistical Summary of Breathing Zone and Area Sampling Results for the Various Fume Constituents

Table B-1
Breathing zone-high volume-open space

Contaminant	Arithmetic results			Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ * Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	173.8	99.7	57	129.5	2.7	23-315 15,000
Iron	3	26.7	15.3	57	22.4	2.1	10.9-47.4 10,000
Total chromium	3	4.2	3.0	71	2.9	3.0	0.9-8.1 1,000
Nickel	3	8.2	5.3	65	5.4	3.7	1.2-14.0 1,000
Hexavalent chromium ^a	3	3.0	1.4	47	2.6	2.1	1.5-4.4 50
Manganese	3	4.3	3.1	72	3.2	2.7	1.2-8.6 5,000

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

+ 1. 10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.

2. 1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.

3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14).

ϕ Coefficient of variation = standard deviation $\div$ mean.

42/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table B-2
High volume-confined space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL, being considered, $\mu\text{g}/\text{m}^3$ **
Total dust and fume	5	238.4	94.2	40	218.1	1.6	125-356	15,000
Iron	3	22.1	8.9	40	19.8	1.9	9.8-31.0	10,000
Total chromium	3	3.6	1.1	31	3.5	1.4	2.7-5.2	1,000
Nickel	3	11.5	3.0	26	11.0	1.4	7.2-13.6	1,000
Hexavalent chromium ^a	3	2.0	0.5	25	2.0	1.4	1.6-2.5	50
Manganese	3	3.1	0.5	16	3.0	1.3	2.3-3.6	5,000

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.+ 1. 10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.2. 1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14). ϕ Coefficient of variation = standard deviation $\div$ mean.

Table B-3
HVLV-open space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	384	88	23	373	1.3	260-500	15,000
Iron	3	44.0	16.3	37	41.4	1.5	32.5-67.1	10,000
Total chromium	3	14.9	3.3	22	14.6	1.3	12.5-19.6	1,000
Nickel	3	8.6	7.2	84	6.0	2.9	2.4-18.7	1,000
Hexavalent chromium ^a	3	2.5	1.4	56	2.2	1.9	1.5-4.4	Several options being considered ⁺
Manganese	3	11.4	3.3	29	11.0	1.4	9.0-16.1	5,000

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.+ 1. 10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.2. 1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14). ϕ Coefficient of variation = standard deviation $\div$ mean.

44/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table B-4
HVL V-confined space

Contaminant	Arithmetic results			Geometric results					
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ *	OSHA PEL being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	1,733	435	25	1,678	1.3	1159-2357	15,000	
Iron	3	132.4	26.0	20	129.9	1.3	103.4-166.4	10,000	
Total chromium	3	65.4	24.5	37	60.1	1.6	36.1-96.2	1,000	
Nickel	3	25.9	5.6	22	25.3	1.3	18.2-31.0	1,000	15
Hexavalent chromium ^a	3	12.7	9.8	77	8.2	4.2	3.0-22.5	50	Several options being considered ⁺
Manganese	3	50.0	21.9	44	44.4	1.9	22.3-76.0	5,000	

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.+ 1.10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.2.1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14). ϕ Coefficient of variation = standard deviation $\div$ mean.

Table B-5
Handheld shield-confined space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL, being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	5	5,562	3,250	58	4,337	2.4	1068-9906	15,000
Iron	3	409.5	324.3	79	225.2	4.9	38.1-828.2	10,000
Total chromium	3	265.0	212.4	80	144.7	5.0	24.4-541.1	1,000
Nickel	3	43.0	32.4	75	26.0	4.2	5.3-84.5	1,000
Hexavalent chromium ^a	3	124.4	129.0	104	59.4	5.0	12.3-305.2	Several options being considered ⁺
Manganese	3	249.7	193.6	78	146.5	4.4	28.5-500.0	5,000

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

+ 1. 10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.

2. 1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.

3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14).

ϕ Coefficient of variation = standard deviation $\div$ mean.

Table B-7
General area-high volume-open space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL, being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	183	102	56	149	2.1	46-324	
Iron	6	15.9	8.8	55	13.7	1.9	8.2-28.2	
Total chromium	3	2.3	0.8	35	2.2	1.5	1.6-3.5	
Nickel	3	8.1	6.2	77	5.1	3.8	1.2-16.2	
Hexavalent chromium ^a	2	2.6	0.4	15	2.6	1.3	2.2-3.0	
Manganese	3	1.4	0.6	43	1.3	1.7	0.8-2.3	

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

ϕ Coefficient of variation = standard deviation $\div$ mean.

48/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table B-8
General area measured summary-high volume-confined space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL, being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	5	136	83	61	102	2.6	30-237	
Iron	3	15.2	3.2	21	14.9	1.3	12.5-19.7	
Total chromium	3	1.2	0.7	58	0.9	3.5	0.2-1.8	
Nickel	3	5.2	2.6	50	4.3	2.3	1.7-7.9	
Hexavalent chromium ^a	2	2.6	1.0	38	2.4	1.6	1.5-3.5	
Manganese	3	6.3	7.4	117	2.5	5.3	0.7-16.7	

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

ϕ Coefficient of variation = standard deviation $\div$ mean.

Table B-9
General area measurement summary-handheld shield-open space

Contaminant	Arithmetic results			Geometric results				
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL, being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	329	193	59	263	2.2	103-628	15,000
Iron	3	64.5	54.8	85	45.5	2.7	25.7-142.1	10,000
Total chromium	3	19.4	11.6	60	16.3	2.0	9.0-35.6	1,000
Nickel	3	23.5	9.7	41	21.7	1.6	15.4-37.2	1,000
Hexavalent chromium ^a	3	4.1	0.9	22	4.0	1.3	3.0-5.1	50
Manganese	3	9.1	1.6	18	9.0	1.3	7.0-10.7	5,000

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

+ 1. $10 \mu\text{g}/\text{m}^3$ with a $25 \mu\text{g}/\text{m}^3$ ceiling.

2. $1 \mu\text{g}/\text{m}^3$ with a $10 \mu\text{g}/\text{m}^3$ ceiling.

3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or $50 \mu\text{g}/\text{m}^3$) (Ref. 14).

ϕ Coefficient of variation = standard deviation $\div$ mean.

Several options
being considered⁺

50/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table B-10
General area measurement summary-handheld shield-confined space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	5,201	3,574	69	3,849	2.5	1192-10,235	15,000
Iron	3	312.3	206.6	66	216.5	3.3	56.9-562.9	10,000
Total chromium	3	301.2	200.5	67	212.7	3.2	59.6-550.5	1,000
Nickel	3	41.8	31.6	76	28.8	3.1	8.9-84.5	1,000
Hexavalent chromium α	3	219.5	167.8	76	116.6	5.4	17.4-428.4	50
Manganese	3	230.6	209.9	91	140.7	3.5	42.2-523.5	5,000

* TWA for up to a 10 hour workday, 40 hour work week.

α Only the water soluble variety was found.

+ 1. 10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.

2. 1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.

3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14).

ϕ Coefficient of variation = standard deviation $\div$ mean.

Several options
being considered⁺

Table B-11
General area measurement summary-high velocity-low volume-open space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL, being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	227	172	76	143	3.3	30-488	15,000
Iron	3	15.3	6.0	39	14.1	1.6	8.6-23.2	10,000
Total chromium	3	8.9	3.2	36	8.3	1.7	4.7-12.3	1,000
Nickel	3	3.5	2.5	71	2.7	2.4	1.2-7.0	1,000
Hexavalent chromium ^a	3	3.3	1.3	39	4.1	1.1	1.5-4.4	Several options being considered ⁺
Manganese	3	8.3	1.6	19	8.1	1.3	6.1-9.9	5,000

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

+ 1.10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.

2.1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.

3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14).

ϕ Coefficient of variation = standard deviation $\div$ mean.

52/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table B-12
General area measurement summary-high velocity-low volume-confined space

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ * OSHA PEL being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	1,743	636	36	1,595	1.6	705-2,393	15,000
Iron	3	108.2	54.9	51	88.3	2.4	32.7-161.8	10,000
Total chromium	3	69.9	34.6	49	58.6	2.2	24.1-107.8	1,000
Nickel	3	22.0	7.6	35	20.4	1.7	11.4-28.7	1,000
Hexavalent chromium ^a	3	44.1	30.1	68	23.1	5.9	3.0-74.2	50
Manganese	3	58.6	32.5	55	47.4	2.4	18.2-97.9	5,000

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

+ 1.10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.

2. 1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.

3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14).

ϕ Coefficient of variation = standard deviation $\div$ mean.

Several options being considered⁺

Table B-13
Area measurements-air purifying helmet

Contaminant	Arithmetic results				Geometric results			
	Number of measurements	Mean, $\mu\text{g}/\text{m}^3$	Standard deviation, $\mu\text{g}/\text{m}^3$	Coefficient of variation, percent ϕ	Standard deviation, factor	Measurement range, $\mu\text{g}/\text{m}^3$ *	Current OSHA PEL, $\mu\text{g}/\text{m}^3$ *	OSHA PEL being considered, $\mu\text{g}/\text{m}^3$ *
Total dust and fume	6	46,868	5,924	13		41,855-54,362	15,000	
Iron	3	4,298.7	782.7	18		3,652.1-5,400.0	10,000	
Total chromium	3	3,153.4	484.6	15		2,706.6-3,826.8	1,000	
Nickel	3	379.8	57.4	15		339.0-461.0	1,000	
Hexavalent chromium ^a	3	2,260.6	199.2	9		2,012.2-2,500.0	50	Several options being considered ⁺
Manganese	3	2,739.3	499.1	18		2,296.1-3,436.6	5,000	

* TWA for up to a 10 hour workday, 40 hour work week.

^a Only the water soluble variety was found.

+ 1. 10 $\mu\text{g}/\text{m}^3$ with a 25 $\mu\text{g}/\text{m}^3$ ceiling.

2. 1 $\mu\text{g}/\text{m}^3$ with a 10 $\mu\text{g}/\text{m}^3$ ceiling.

3. The lowest technologically feasible TWA with no ceiling or with an appropriate ceiling (such as 10, 25, or 50 $\mu\text{g}/\text{m}^3$) (Ref. 14).

ϕ Coefficient of variation = standard deviation $\div$ mean.

Appendix C: Correlations Among Fume Constituents

Linear correlations were performed among the various fume constituents and the results are presented in the following figures.

Linear: $Y = \text{Intercept} + \text{Slope} \cdot X$

R-squared = .8937 8.93743E-01
 Intercept = 9.1951 9.19507E+00
 Slope = .0079 7.87584E-03

Source	Df	SS	MS	F
Regression	1	6283.223	6283.223	151.400
Residual	18	747.015	41.501	
Total	19	7030.238		

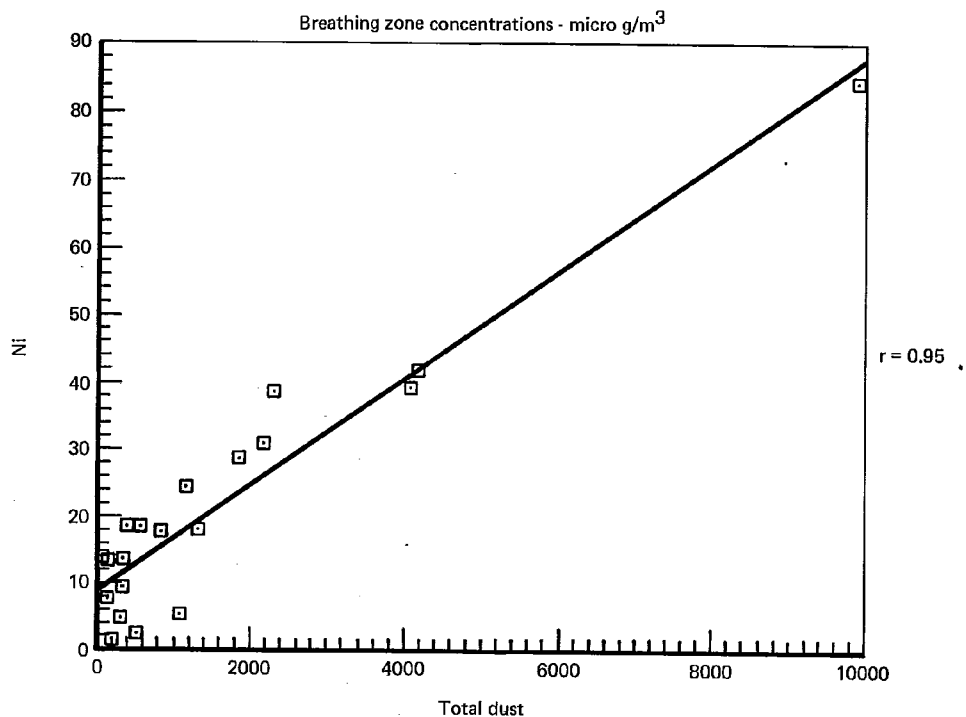


Fig. C.1—Nickel and total dust

56/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Linear: $Y = \text{Intercept} + \text{Slope} \times X$

R-squared = .9762 9.76240E-01
 Intercept = -16.6923 -1.66923E+01
 Slope = .0538 5.38352E-02

Source	Df	SS	MS	F
Regression	1	293575.956	293575.956	739.587
Residual	18	7145.021	396.946	
Total	19	300720.977		

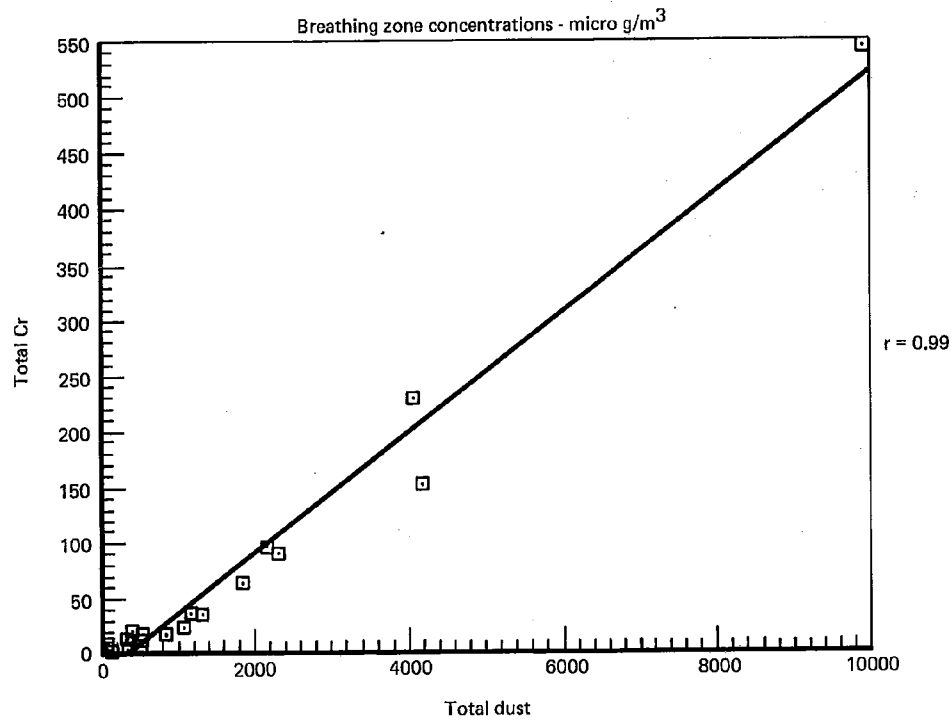


Fig. C.2—Total chromium and total dust

Linear: $Y = \text{Intercept} + \text{Slope} \cdot X$

R-squared = .9047 9.04697E-01

Intercept = .7801 7.80094E-01

Slope = .0911 9.11376E-02

Source	Df	SS	MS	F
Regression	1	841363.337	841363.337	170.871
Residual	18	88631.340	4923.963	
Total	19	929994.677		

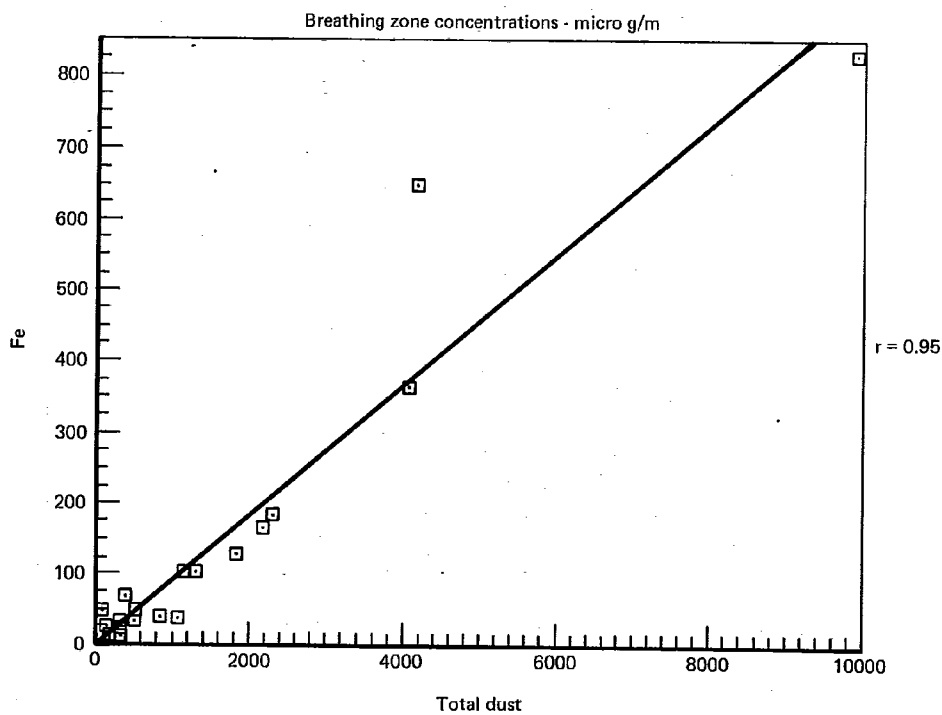


Fig. C.3—Iron and total dust

58/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Linear: $Y = \text{Intercept} + \text{Slope} * X$

R-squared = .9159 9.15856E-01

Intercept = -10.9955 -1.09955E+01

Slope = .0332 3.31855E-02

Source	Df	SS	MS	F
Regression	1	88252.482	88252.482	163.266
Residual	15	8108.140	540.543	
Total	16	96360.622		

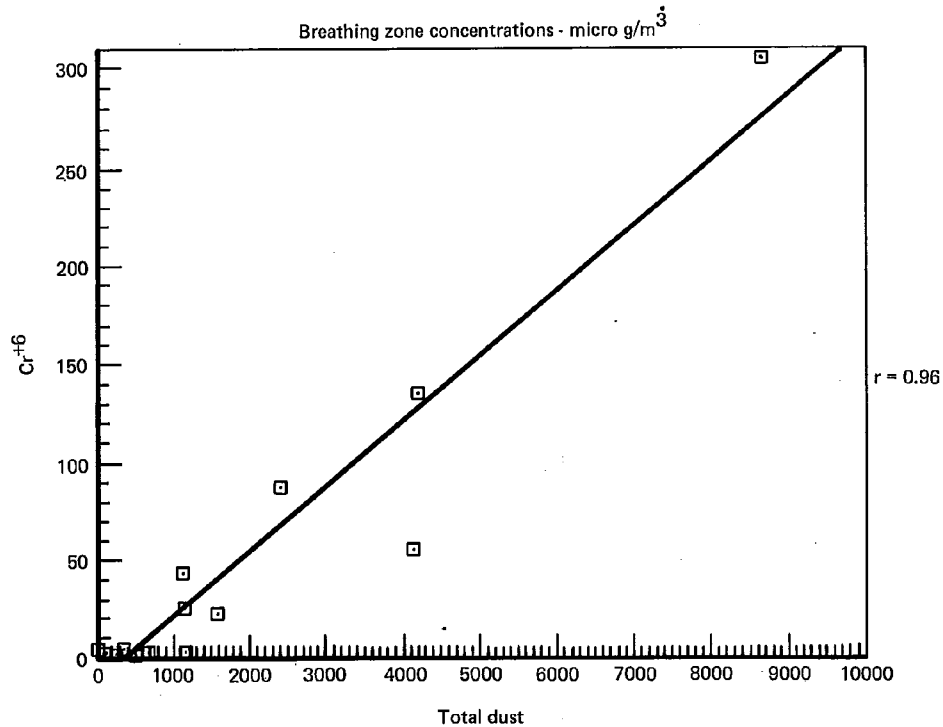


Fig. C.4—Hexavalent chromium and total dust

Linear: $Y = \text{Intercept} + \text{Slope} \cdot X$

R-squared = .8583 8.58346E-01
Intercept = 11.0482 1.10482E+01
Slope = .1450 1.45023E-01

Source	Df	SS	MS	F
Regression	1	6483.850	6483.850	121.189
Residual	20	1070.043	53.502	
Total	21	7553.893		

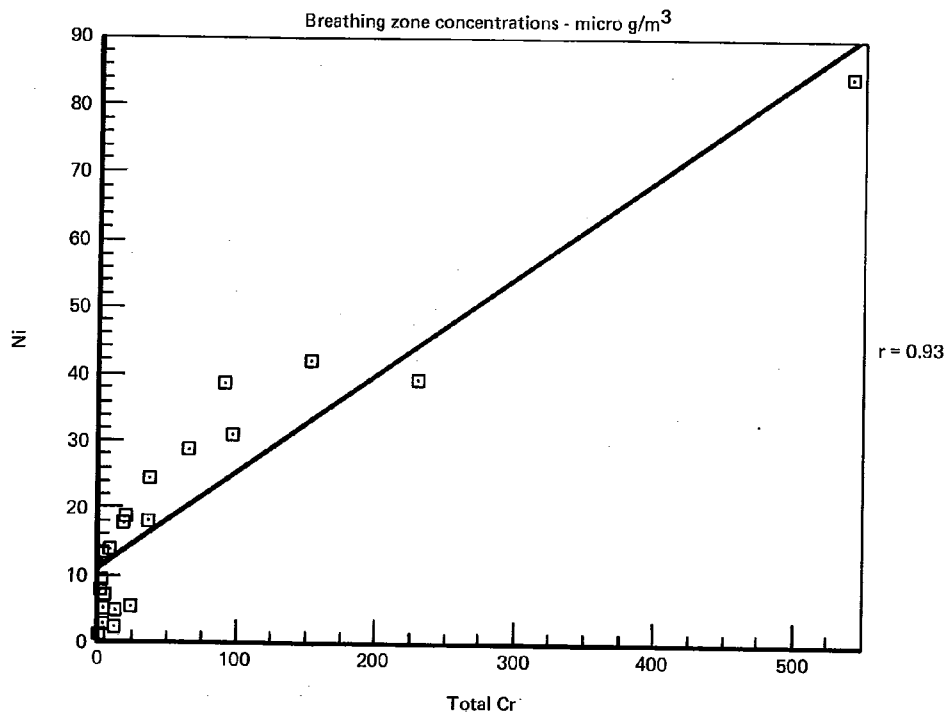


Fig. C.5—Nickel and total chromium

60/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Linear: $Y = \text{Intercept} + \text{Slope} * X$

R-squared = .9923 9.92321E-01
 Intercept = -38.8118 -3.88118E+01
 Slope = .0682 6.81652E-02

Source	Df	SS	MS	F
Regression	1	27750457.6576 M7D.3D	27750457.6576 M7D.3D	5557.000
Residual	43	214732.713	4993.784	
Total	44	27965190.3702 M7D.3D		

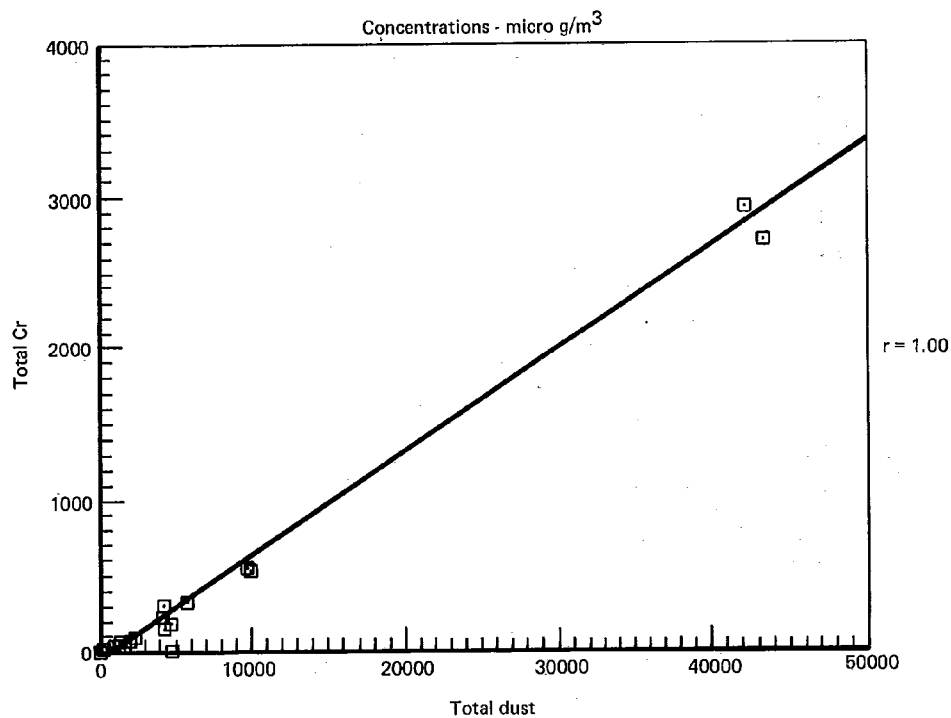


Fig. C.6—Composite total chromium and total dust

Linear: $Y = \text{Intercept} + \text{Slope} \cdot X$

R-squared = .9840 9.83978E-01
 Intercept = 8.1451 8.14510E+00
 Slope = .0080 8.00951E-03

Source	Df	SS	MS	F
Regression	1	383139.570	383139.570	2640.846
Residual	43	6238.532	145.082	
Total	44	389378.102		

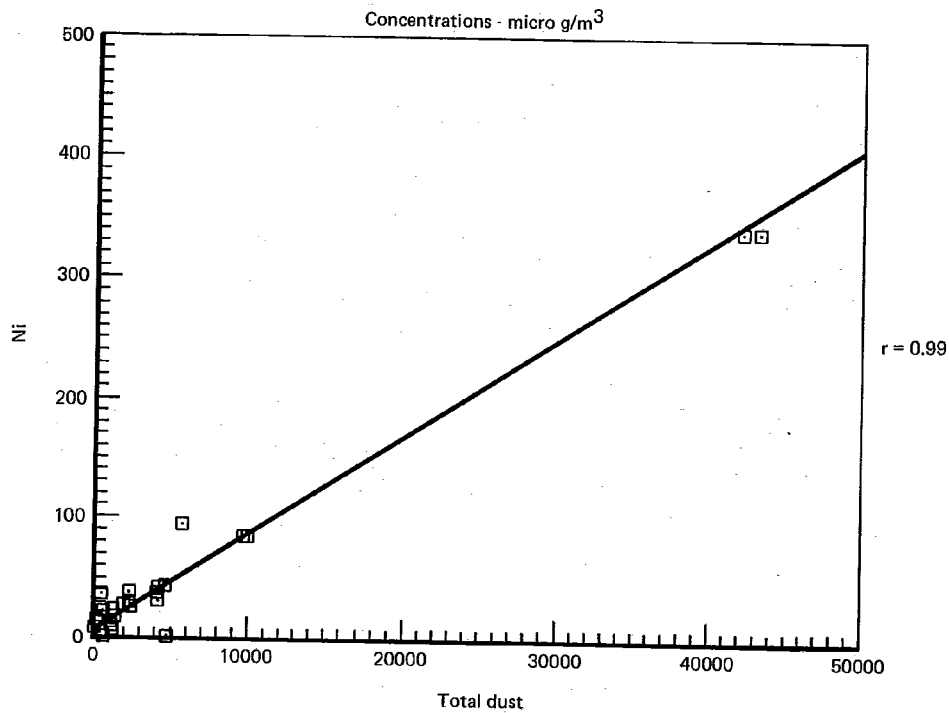


Fig. C.7—Composite - nickel and total dust

62/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Linear: $Y = \text{Intercept} + \text{Slope} \cdot X$

R-squared= .9877 9.87722E-01

Intercept = -23.6364 -2.36364E+01

Slope = .0928 9.27519E-02

Source	Df	SS	MS	F
Regression	1	51379540.6584 M7D.3D	51379540.6584 M7D.3D	3459.111
Residual	43	638695.885	14853.393	
Total	44	52018236.5432 M7D.3D		

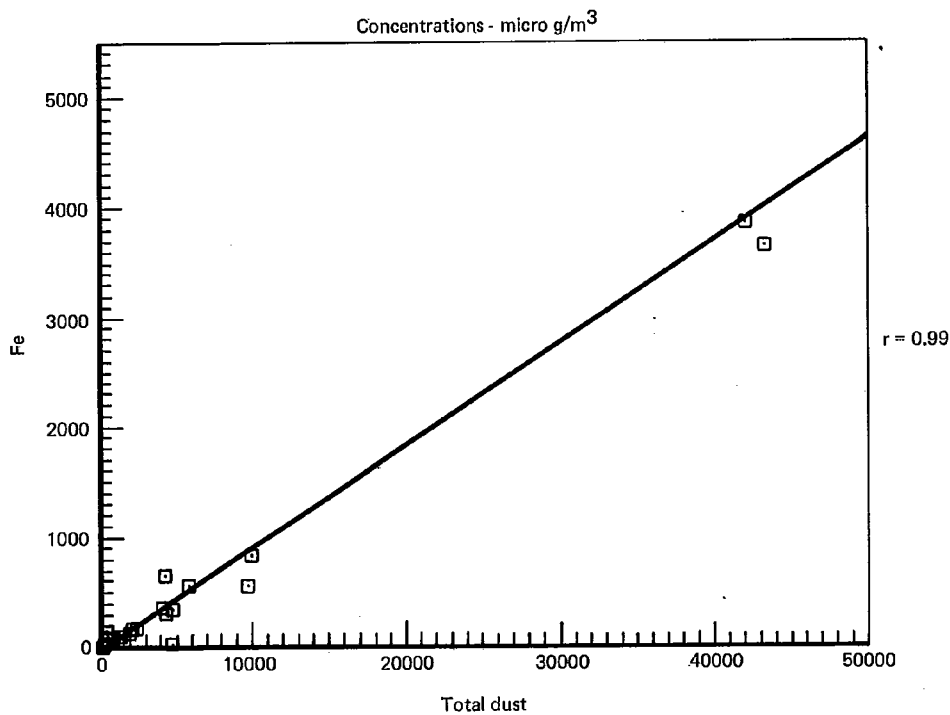


Fig. C.8—Composite - iron and total dust

Appendix D: Lapel Versus In-Helmet Sampling Results

For comparative purposes, a small number of lapel and in-helmet samples were taken simultaneously under four different testing conditions. The results are presented in Table D-1, including total particulate as well as metals. Lapel to in-helmet ratios varied between 0.04 and 2.69. Generally, it appears that larger and more consistent ratios occurred when high concentrations were measured, as in the no-control/open space

testing condition. Data obtained under the no-control testing condition produced ratios greater than 1 (ranging from 1.0-1.64) for total particulate and all of the metals. Measurements made in the other test conditions produced concentration results that were about an order of magnitude lower, and the lapel to in-helmet ratios covered a much larger range (0.04-2.69).

64/WELDING FUME CONTROL: A DEMONSTRATION PROJECT

Table D-1
Lapel and in-helmet measurement comparisons, measurement results, and lapel/in-helmet ratios

Testing condition	Total particulate		Nickel		Manganese		Iron		Total chromium	
	Actual measurements, $\mu\text{g}/\text{m}^3$	Ratio	Actual measurements, $\mu\text{g}/\text{m}^3$	Ratio	Actual measurements, $\mu\text{g}/\text{m}^3$	Ratio	Actual measurements, $\mu\text{g}/\text{m}^3$	Ratio	Actual measurements, $\mu\text{g}/\text{m}^3$	Ratio
No control-Open space	3674/2300	1.60	38.7/38.7	1.0	138.4/84.3	1.64	267.4/182.6	1.46	139.5/90.6	1.54
	5140/4186	1.23	58.1/41.9	1.39	22.6/16.7	1.35	648.4/392.6	1.65	204.4/152.3	1.34
HVLV-Open space	166/307	0.54	1.3/4.7	0.28	0.4/9.1	0.04	15.3/32.5	0.47	1.9/12.5	0.15
	119/500	0.24	1.2/2.4	0.50	0.5/9.0	0.06	14.5/32.5	0.45	1.8/12.6	0.14
High volume-Open space	259/185	1.40	3.5/1.2	2.69	0.5/1.2	0.42	10.1/10.9	0.93	1.6/0.9	1.78
	170/322	0.53	5.1/13.6	0.38	1.4/3.2	0.44	19.0/9.8	1.94	1.5/3.1	0.48

Appendix E: Chemical Analysis of Fume

The fume generated by the E-308-16 electrode was analyzed by the AWS Project Committee on Fumes and Gases. The results are shown in Table E-1. When the total amount of fume collected is such that the

total chromium is less than 50 micrograms (detectability limit), then the chromium value must be projected by multiplying the percent in the fume by the total weight collected. This will apply to nickel as well.

Table E-1
E308-16 fume analysis
(expressed as percent by weight)

Element	Percentage
Total chromium	5.57
Soluble Cr VI	4.12
Insoluble Cr VI	0.30
Non Cr VI	1.15
Iron	10.8
Nickel	0.75
Manganese	6.2
Total fluoride	16.8
Potassium	18.9
Sodium	10.4
Silicon	4.9