DEMONSTRATION OF AIR CONTAMINANT CONTROL METHODS FOR TORCH CUTTING AND AIR CARBON-ARC GOUGING

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DISCLAIMER

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ABSTRACT

This study was undertaken to develop ventilation guidelines for air carbon-arc gouging and torch cutting, processes which produce some of the highest exposures to metal particulate in industry. The study was directed toward finding solutions for processing of large workpieces. It was undertaken by constructing prototype test booths within a foundry cleaning and finishing area and conducting tests on actual production activities within the booths. Two different approaches were tried, both of which proved to be successful in controlling worker exposure during normal production activities. These approaches consisted of unilateral flow booths, both horizontal flow and downdraft, and "push-pull" tunnels. Limits were found to the controllability these methods could provide, however, when air carbon-arc gouging was conducted in confined conditions. Besides protecting the process operator, these methods also isolate a very significant source of contamination from the general workplace environment. Besides the processes evaluated, these methods should also find application during welding and chipping and grinding with portable tools.

This study was limited to processing of steel and this work should be extended to establish ventilation rates and limits of controllability for other common workpiece materials such as stainless steel, other high alloy steels, and nickel and copper alloys.

CONTENTS

FIGURES

(continued)

(continued)

FIGURES (continued)

TABLES

ACKNOWLEDGEMENT

The study team wishes to acknowledge the contribution of Maynard Steel Casting Company of Milwaukee, WI whose active participation made this NIOSH study possible. Maynard was a natural candidate for the study because its staff was in the midst of designing ventilation measures for a large new foundry cleaning and finishing facility which was then in the first stages of construction. It was hoped that insights gained by this research would be helpful in devising practical and effective ventilation measures for the new facility. The Maynard contribution to the study was very significant. The foundry financed the construction of the test booths, provided process operators for the tests, and furnished assistance and input to the study team on a continuous basis. Many individuals and departments were involved, but special thanks go to Mr. Robert Korevec, Mr. William Slawnik, Mr. Milton Rauguth, Mr. Walter Wilms and Mr. Gene Wabiszewski.

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INTRODUCTION

STATEMENT OF THE PROBLEM

In 1979, the Steel Castings Research and Trade Association (SCRATA) of Great Britain concluded from studies of steel foundry cleaning and finishing areas that the air carbon-arc process posed the most significant hazards from overexposure to dust and fume (1).

In a 1980 nationwide study of American foundries alloying with nickel and chromium and using state-of-the-art ventilation control measures, the highest worker exposures by far to airborne metal particulate were measured for manual torch cutting and gouging operations within the cleaning and finishing area (2). These operations are also common to large fabrication shops and maintenance departments. Although some of these processes are amenable to isolation and automation, a large percentage of the work, because of the complex, one-of-a-kind nature of the work tasks, will continue to be performed manually for many years to come.

Exhaust control of these processes at the source is very difficult because of the large quantities of contaminants emitted and the violent dispersion velocities created by the tools themselves. Unlike welding, where shielding gases are used to minimize fume generation, cutting and gouging processes attempt to maximize metal removal rates by enhancing fume generation. For example, Figure 1 shows a sketch of the air carbon-arc gouging process in which a copper-clad carbon/graphite electrode is used to melt metal while a high pressure air nozzle, mounted on the electrode holder, speeds metal removal both through oxidation and by blowing away molten metal droplets. Other common torch cutting processes include oxy-fuel, plasma and powder cutting.

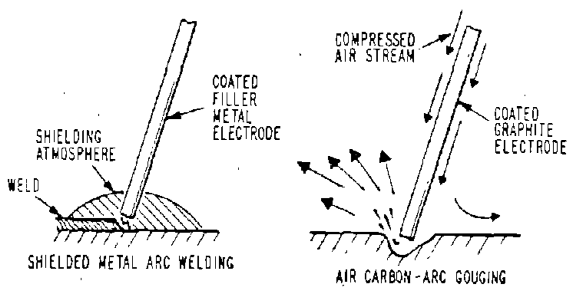

Figure 1. Comparison of the protective atmosphere of welding with the violent action of the air carbon-arc gouging process.

Evaluations of torch cutting and gouging operations in industry reveal that ventilation control is not always applied and that processing of small workpieces is much more likely to be controlled than work on very large workpieces, 1.5 m (5 ft) in major dimension or larger. Often the reason for not attempting ventilation control of large work is the prohibitive amount of ventilation energy required. Rarely is the work isolated to any degree and fugitive emissions from these operations cross-contaminate large air spaces occupied typically by crane operators, fork lift drivers, supervisors, welders and grinders. The extent of the toxic hazard depends on the metals being processed, which are typically low-carbon steel, but also can include nickel and chromium alloys, copper-based alloys, and high-manganese steels, among others.

Ventilation approaches to these processes vary widely and so does the effectiveness of air contaminant control. Reviewing the literature and observing actual practice, it is apparent that ventilation designers have little to work with in terms of practical guidelines which can help to increase effectiveness and minimize energy consumption. The research which has been done to develop better ventilation approaches for these processes has centered around the processing of small workpieces on semi-enclosed benches. Little study has been directed at the manual processing of large workpieces.

It is apparent that torch cutting and gouging processes require and deserve further study to develop and test suitable approaches that will reduce worker exposures.

PROGRAM OBJECTIVE

The goal of this demonstration project was to establish, through experiments conducted in an actual industrial setting, guidelines for ventilation methods to effectively control worker exposure to air contaminants during torch cutting and air carbon-arc gouging. Since the greatest problems with implementing effective control measures have been encountered when the workpiece is large and at times relatively immobile, and since little research has been devoted to this problem, this project concentrated on developing control parameters for that class of work.

BACKGROUND

In this section, published information concerning the nature and control of air contaminants during torch cutting and air carbon-arc gouging will be described and discussed, as well as other ventilation research findings which are pertinent to this demonstration project.

Field Studies

Shipbuilding Industry--

In 1968, a field study was reported in which worker exposures were measured during air carbon-arc gouging of steel in three different ventilation conditions during shipbuilding: work on a bench in a ventilated booth, work in the open outdoors, and work in a semi-enclosed space (3). Mechanical ventilation was applied in only the first of the three conditions, and at an exhaust rate so low that no conclusions can be drawn from this work concerning the potential for reducing worker exposures by that means. However, the results are still useful because some potentially hazardous air contaminants associated with this process were identified as well as the effect of production rate on exposure.

In the least confined condition (open air), copper fume exposure measured under the welding helmet was always significant, ranging from 2-14 times the present Permissable Exposure Limit (PEL) of 100 $\mu g/m^3$*. Copper fume was produced through consumption of the copper-clad electrodes used in this process. The highest exposures occurred, as expected, at higher metal removal rates. Lead and iron oxides were below their PEL's [50 $\mu g/m^3$ and 10 mg/m^3, respectively] at lower metal removal rates, but they exceeded these limits at higher removal rates. Manganese, ozone, carbon monoxide, carbon dioxide, nitrogen dioxide, and nitric oxide were all well below their PEL's.

When the process was performed in the least ventilated condition (semi-confined space), copper, iron and lead exposures increased dramatically and ozone and carbon monoxide exceeded their PEL's of 0.1 and 50 ppm, respectively. Manganese, carbon dioxide and the nitrogen oxides remained below their limits.

Steelmaking Industry--

In 1969, the findings were reported of a Pennsylvania Dept. of Health study at five steel manufacturing plants which used air carbon-arc gouging and powder burning as production processes (4). In the powder burning process, an acetylene torch utilizes a mixture of acetylene gas, oxygen, and finely divided iron powder. In the majority of cases, these processes were performed in metal partition booths without ceilings. Some of the booths incorporated sidedraft ventilation (no details were given) while others relied on roof ventilators to control exposures through general ventilation, or used mancooler fans to blow the fume away from the worker. Only exposures to iron were assessed and samples were gathered inside the helmet.

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*In this and all subsequent references to allowable limits, the present standards of the Occupational Safety and Health Administration (OSHA) will be used.

The results demonstrated the significant impact that local exhaust ventilation can have on worker exposure. Using general ventilation, iron exposures during both processes were several times the PEL on the average; local exhaust ventilation reduced iron exposures to below the PEL in all cases. Powder burning produced, on the average, somewhat higher iron exposures than did the air carbon-arc trimming and gouging processes. Unfortunately, the absence of both production and ventilation specifics prevents the drawing of general conclusions from these data.

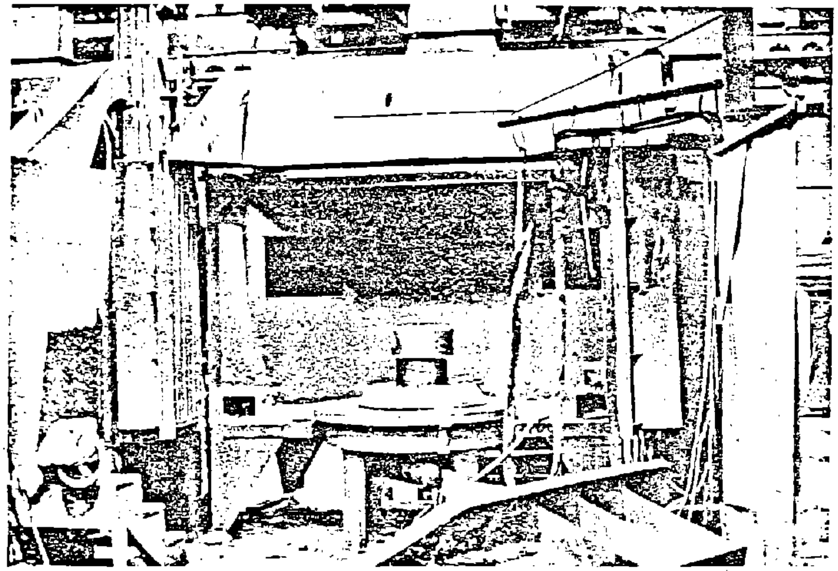
Foundry Industry--

As part of a 1978 NIOSH evaluation of the state-of-the-art of occupational health hazard control technology in the foundry industry, ventilation measures were evaluated during torch cutoff of casting appendages using oxy-acetylene torches as well as during material removal and casting defect correction using air carbon-arc electrodes in steel foundries (5). The air carbon-arc process was ventilated by backdraft hoods behind either fixed work benches for small castings or 0.9 to 1.8 m (3 to 6 ft) diameter powered turntables for larger work within semi-enclosed booths (Figure 2). The turntables were installed specifically to permit easy repositioning of the castings (foot pedal control) so that the fume carried with the pressurized air as it rebounded off the casting could be aimed at the exhaust hood for more direct evacuation. This provision kept the worker in a relatively restricted area while he worked and fresh air was blown across his body during warm weather from supply air vents behind and to either side of him. The workers at fixed work benches also had supply air ducts behind them.

Air samples taken under the welding helmet indicated that copper and iron were controlled at or below their PEL's in 85 percent of the cases. Manganese, nickel, chromium and zinc exposures were always below the allowable limits and lead was not detected. Visual observations indicated that when fume capture was not direct, the fume would roll from in front of to behind the worker where it was inducted into the air moving past the worker.

It was also found during this study that exposures varied significantly among the various workers sampled during the evaluation and that the differences could not be attributed to production rate. Observation failed to identify which practices had a significant effect on exposure, but there were at least two that the study report indicated could have: differences in the way castings were positioned and differences in the position assumed by the worker. The study concluded that, because they are an important factor in the ultimate effectiveness of these ventilation control measures, work practices should be further investigated.

In the same study, a foundry was evaluated in which large appendages were cut off of castings weighing many tons using an oxyacetylene torch in a large open-faced booth, the floor of which was a mobile non-rotating platform upon which both worker and workpiece were stationed (Figure 3).



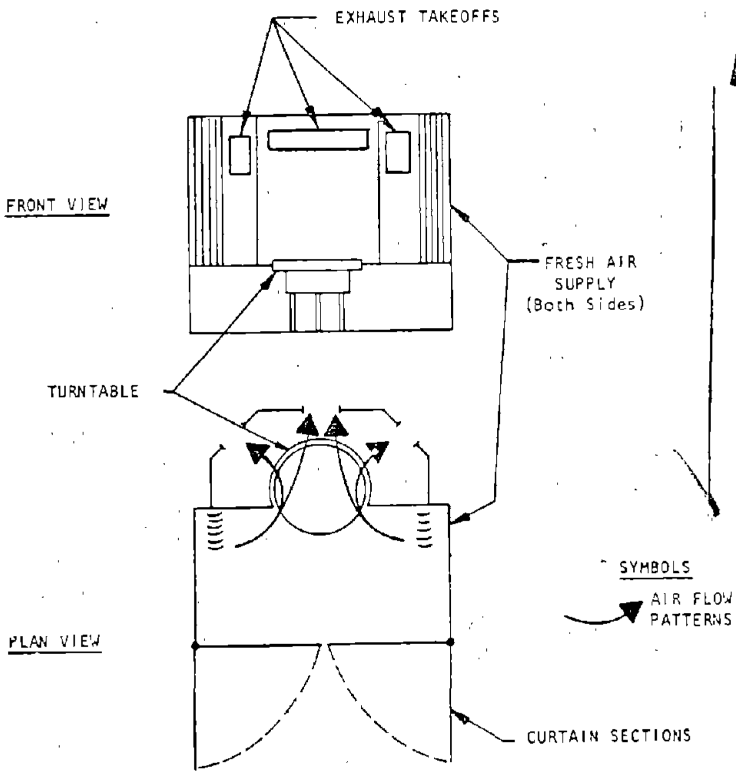


Figure 2. Ventilated open booth with turntable for air carbon-arc gouging of medium sized castings (5).

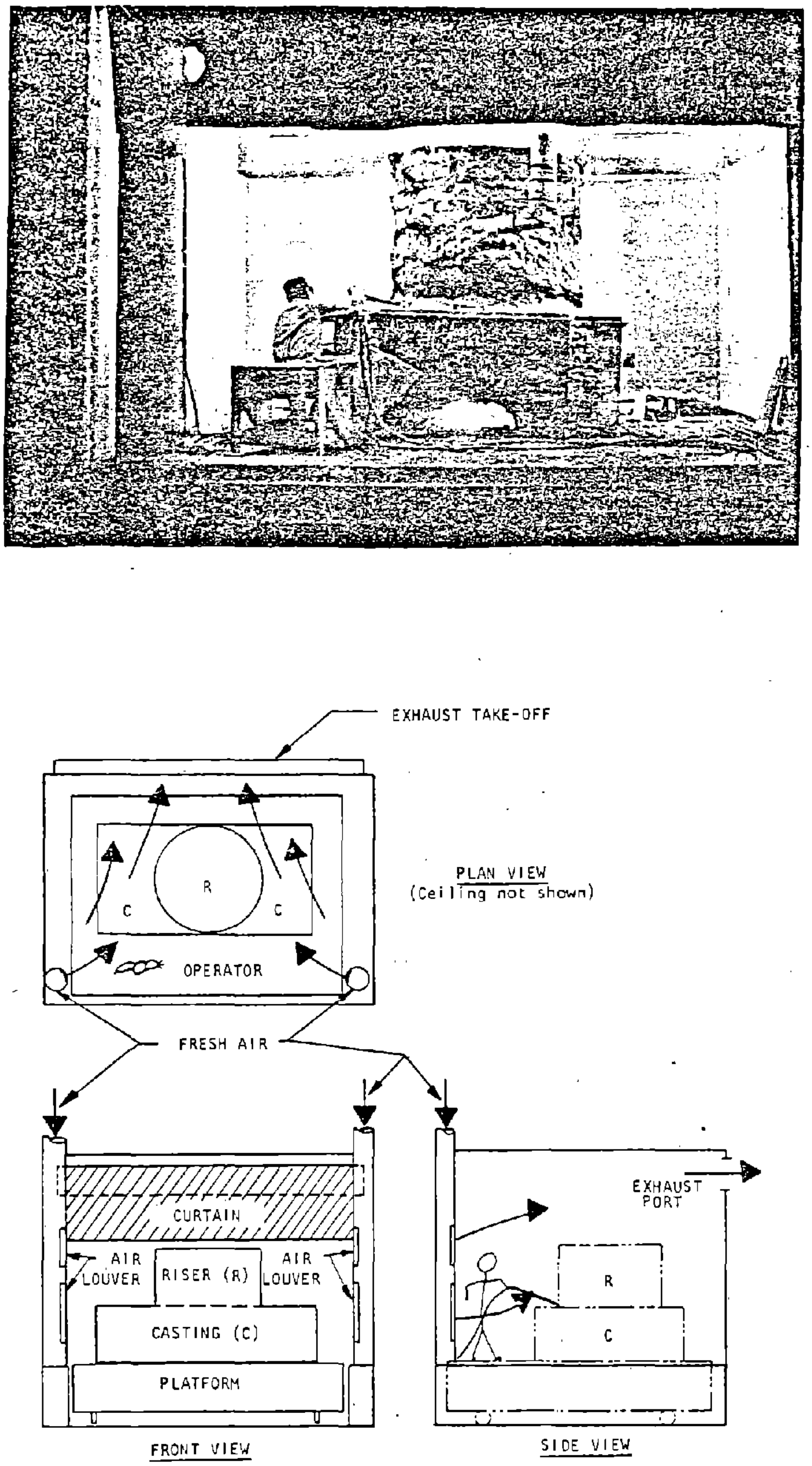


Figure 3. Cutoff of appendages from large casting using oxyacetylene torch (5).

Air was exhausted at the top rear of the booth. During warm weather, eighty percent of this ventilation air was supplied from the outdoors through two adjustable fresh air manifolds on either side of the entrance of the booth.

In this case, exposure to iron was measured at less than half that of the air carbon-arc work described above; as expected, copper exposure was not a problem because of the absence of the copper coated electrodes and lead was not present to a measureable degree.

Observations again attested to the dependency of capture effectiveness on the direction of the air blast from the torch. And, as before, exhaust rate alone was not able to overcome the fume "rolling" which occurred when the air blast was not directed straight at the exhaust end of the booth.

Subsequent to the NIOSH control technology assessment, another study of control technology in the foundry industry was conducted by an ad hoc association of foundries, the Foundry Nickel Committee (2). The intent of this study was to determine the effectiveness of engineering control measures in reducing worker exposures to nickel and chromium in alloy foundries and to identify improvements which could be made to further reduce levels to the limits being considered by OSHA. Six foundries using control methods representing the state-of-the-art were selected for field evaluations.

Considering both fume and dust producing foundry processes, the highest exposures to nickel and chromium were received from torch cutting and air carbon-arc gouging processes (Table 1). The wide variability in exposure levels measured for individual processes was attributed to variations in alloy compositions used as well as differences in production rate, casting size, and ventilation control measures. These factors were interrelated and could not be isolated in this study to establish the effect of each factor on the data. Although nickel, chromium and iron concentrations were all below present PEL's, nickel would exceed the NIOSH recommended limit of 15 $\mu g/m^3$ during torch cutting and gouging by a factor of up to 60 times (6). In addition, almost half of the exposure samples from torch cutters and gougers contained some hexavalent chromium (range of 0.6 to 3.9 $\mu g/m^3$).

Twelve steel foundries were assessed as part of SCRATA's investigation of dust and fume exposures in typical cleaning and finishing areas during 1978-9 (1). Average respirable particulate levels of the combined foundries for ventilated cleaning and finishing processes are presented below:

Table 1. Summary of nickel and chromium exposure data - Foundry Nickel Study (2).

Process	No. of measurements	Nickel exposure, $\mu g/m^3$ *		Chromium exposure, $\mu g/m^3$ *	
		Measurement range	Arithmetic mean	Measurement range	Arithmetic, mean
Torch cutting and air carbon-arc gouging	11	7-900	233	6-270	143
Welding	14	20-560	94	19-290	81
Grinding with portable tools	25	<5-440	94	10-330	95
Swing grinding and cutoff	3	13-30	19	10-36	23
Melting of scrap	15	<5-62	21	<3-82	34
Pouring into molds	7	<4-35	14	7-75	24

*Present OSHA PEL: 1000 $\mu g/m^3$.

Process	No. of measurements	Average respirable particulate exposure, (outside helmet) mg/m^3
Air carbon-arc	27	10.35
Welding	34	2.70
Swing frame grinding	8	1.78
Portable chipping and grinding	35	1.77
Pedestal grinding	13	1.64
Powder cutting	5	1.40

This ordering of processes by exposure level is consistent with the Foundry Nickel Study. In light of the Pennsylvania Dept. of Health study, however, the results for powder cutting are surprisingly low.

Respirable crystalline silica was always less than 1 percent for all of the cleaning and finishing processes which produced fume. It was noted, however, that silica could still be a problem because oxy-fuel cutting was often carried out on floors covered with sand, which could be the source of exposure when it is disturbed by the force of the jet.

In stating that the problems with control of air carbon-arc gouging were worse than they had suspected, SCRATA attributed these problems to inadequate ventilation, i.e. exhaust rates were too low, booth designs were inefficient, and the systems were improperly maintained. Scrutiny of control measures also revealed poor ergonomic design of booths in some cases and cold drafts where exhaust rates were very high.

In a subsequent paper, SCRATA highlighted some of the ventilation methods for the control of air carbon-arc fume which had been investigated in the former study (7). Where large castings were processed, a backdraft booth was utilized with the casting set in a stationary position within the booth. Dimensional and air flow details of this booth are presented in the paper.

Research and Development Projects

Although field inspections reveal problems with control of fume during torch cutting and air carbon-arc gouging for all sizes of workpieces, reported research efforts have concentrated on small workpieces processed on benches. In 1973, design parameters were presented for an enclosed backdraft workbench developed for shipyard applications with an open front face through which the operator worked (8). The bench was tested at indraft velocities of 0.76 and 1.52 m/sec (150 and 300 ft/min). Iron oxide, carbon monoxide and ozone exposures under the welding helmet were found to be well below the PEL's for both conditions, however, copper fume exceeded the PEL at both high and low ventilation rates by factors of 2 and 6, respectively. One of the reasons for the problems experienced with control of copper fume may have been the compact size of the enclosure, designed to be only 30 cm (12 in.) larger than the workpiece. Rebounding of fume off of hood walls and out the front face of the booth probably contributed to the high copper exposures. In a 1974 summary report of dust and fume control in steel foundries, SCRATA presented a hood design which was similar in approach, however, the enclosure was much larger in relation to the workpiece, helping to reduce the rebounding effect. SCRATA (9) recommended a minimum capture velocity of 1.52 m/sec (300 ft/min) at the point of operation.

A recent report from SCRATA (1981) has documented the development of an improved model of the enclosed and ventilated workbench for small workpieces. With previous designs, when the worker leaned over the casting in the performance of the work, his head was inside the front face of the hood and he was subject to the fume contained therein. SCRATA's new design, termed the "Arcstract" system, isolated the worker's head to outside the enclosure and at the same time reduced the required face area through which to work. This was accomplished by having the worker view the process through an inclined double-glazed observation panel installed at the top of the enclosure. Measurements of fume exposure during air carbon-arc gouging of small steel castings revealed extremely low fume levels and reduced noise exposure using this method.

Present Guidelines for Large Workpieces

In its Industrial Ventilation Manual of Recommended Practice, the American Conference of Governmental Industrial Hygienists (ACGIH) describes a ventilated workbench for torch cutting applications (11). Air is drawn uniformly downward through the entire bench surface at a velocity of 0.76 m/sec (150 ft/min). The primary feature of this method is that the worker can perform the process from a variety of positions around the bench. This method, however, has two notable defects:

1. Only fume generated close to the bench surface and directed either downward or laterally across the bench would be directly captured. It is very easy for the torch to blow the fume away from the capture zone of the bench.

2. Depending on its size and configuration and the way it is placed on the workbench, the workpiece can act as a barrier to the flow of air into the bench.

In the American Foundrymen's Society (AFS) manual of Foundry Environmental Control, Volume 1, a sketch is presented for an enclosed exhaust booth with a retractable roof for moving castings in and out (12). No test data are available in these sources for either of these approaches.

Other Pertinent Research

Present ventilation methods for control of fume exposure during torch cutting and gouging of large workpieces subject the worker to widely different velocity fields which have been shown during research on welding ventilation to have significant impacts on worker exposure due to air turbulence around the worker. As part of a welding ventilation experimental program conducted for the American Welding Society, Battelle Columbus Laboratories measured the effect of prevailing air currents from different directions on worker exposure during welding on a bench (13). Their results indicate that, for welding operations, the velocity field in the immediate vicinity of the worker has a dramatic effect on worker exposure level. In performing these experiments a portable air current generator was constructed which could create a unidirectional air flow field of adjustable speed. Maintaining the work operation stationary, the air current generator was moved to a number of locations around the worker and air was directed at the welding operation. Only horizontal velocity fields were tested at air speeds from 0.25 to 1.0 m/sec (50 to 200 ft/min). Data from these experiments were presented in terms of fume concentration ratios, calculated as the worker exposure under the influence of a particular velocity field (Cv) to the worker exposure with no prevailing air currents other than the thermal drafts caused by the welding itself (Cv_o). Graphs showing the relationships between concentration ratio, Cv/Cv_o, and air speed for three selected velocity fields are shown in Figure 4. As expected, increasing air speed had the net effect of decreasing the Cv/Cv_o ratio, but in different fashions depending on the direction of the air. Air motion from the side as low as 0.25 m/sec (50 ft/min) effectively reduced worker exposures to ten percent of the Cv_o value. Air motion from the back, on the other hand, caused an increase in the concentration ratio at low air speeds. When air speed was increased, the ratio began to decrease but, in the air speed range tested, it only reduced to about 40 percent of the Cv_o value. The obstacle which the body presents to air flow probably accounts for these differences in exposure levels with different velocity fields. When air flow is from behind, eddy currents directly in front of the worker's body can act to pull contaminants from the fume source toward the worker (Figure 5). This eddy current effect was also measured by Heriot and Wilkerson in an independent study of workers at different positions within a unidirectional flow booth (14).

These findings demonstrate that the velocity field around the worker can have a significant impact on fume exposure and therefore needs to be considered in the development of ventilation approaches.

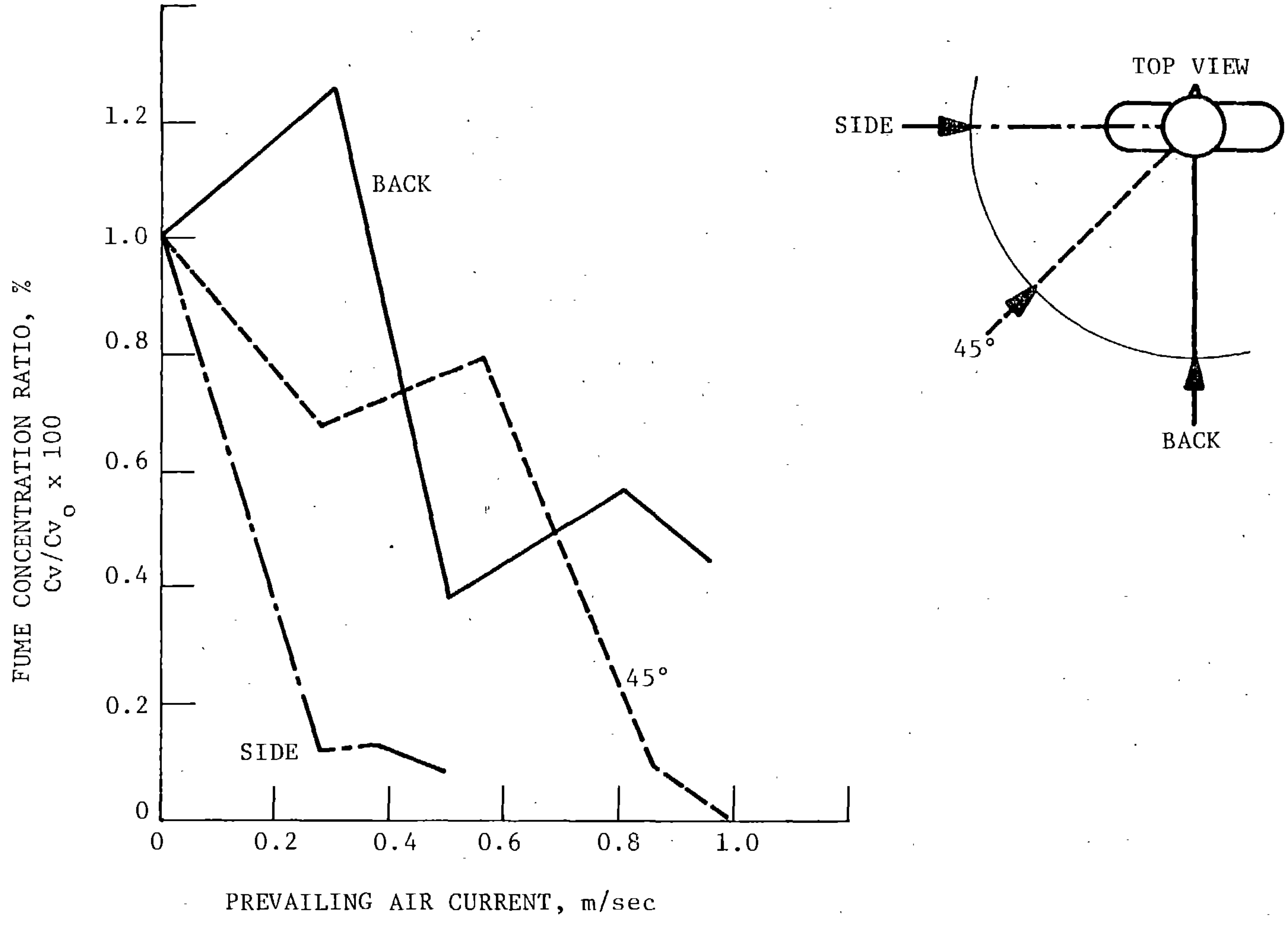


Figure 4. Relationship of worker exposure to prevailing horizontal air velocity fields during welding (13).

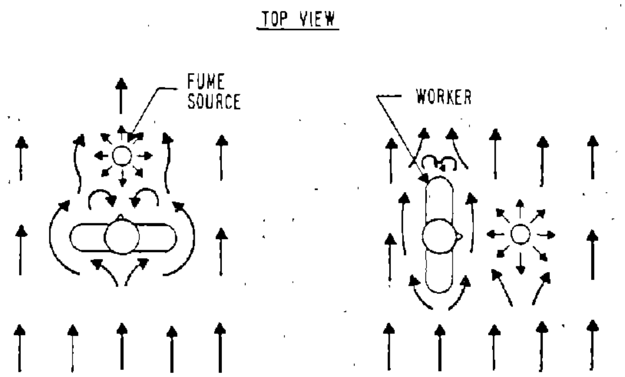


Figure 5. Comparison of the eddy current effects of air turbulence around the worker when the prevailing air currents are from the back (left sketch) or the side (right sketch).

TECHNICAL APPROACH

GENERAL APPROACH

Ventilation approaches for control of worker exposure to air contaminants during torch cutting and air carbon-arc gouging of castings in the foundry cleaning and finishing area were studied in a specially designed test facility located in a steel foundry. In this section, the selection of processes and ventilation approaches for detailed study are discussed as well as the approach to gathering air sampling data.

PROCESSES STUDIED

Five industrial processes were considered for study: oxy-fuel, air carbon-arc, powder burning, plasma cutting, and oxygen lancing. All are used in industry for cutting; the air carbon-arc process, however, is unique in that it can also be used for gouging, a method of removing material around cracks, holes, and defects as a preparation step for welding, as well as for removing unwanted weld material and for "pad washing", a method of removing the remaining protuberances from castings after casting appendages are cut off.

Oxy-fuel torches using a variety of gaseous fuels are in common use in industry for cutting and hole burning. Powder burning is used for metals that cannot be satisfactorily cut with oxy-fuel torches. In powder burning a finely divided, exothermic iron powder is continuously introduced into the cutting oxygen stream. As the powder passes through the torching preheat flames, it ignites, creating an intense heat that can readily and neatly cut through alloy steels, cast iron, and non-ferrous metals.

Plasma arc cutting methods first became popular for cutting aluminum but recently have expanded in their usage to include stainless steel and other alloy steels, cast iron, and copper. This process does not yet compete with oxy-fuel torches on carbon steel. In the basic plasma arc process, an electrode is positioned at the entrance of a constricting orifice through which inert gas, usually argon or nitrogen, is fed. As it passes through the nozzle, the gas is heated to high temperatures by the arc from the electrode. The velocity of the gas is sufficient to blow away metal melted by the plasma arc.

The oxygen lance is a self-consuming torch used to burn through very large sections of metal or concrete. It uses very large quantities of fuel and oxygen. A typical lance consists of a small diameter pipe packed with a bundle of low carbon steel wires.

Air carbon-arc gouging and oxy-fuel cutting were selected for testing for the following reasons:

1. They are common operations employed in the processing of mild carbon steel, which represents the highest volume use of torch cutting and gouging equipment.

2. The air carbon-arc process, when used for pad washing and gouging, is a process which will not be easily automated in the future.

3. They represent both physical (air carbon-arc) and chemical oxidation (oxy-fuel) metal removal methods.

ENGINEERING CONTROL METHODS STUDIED

Selection Criteria

The primary consideration in selecting engineering control measures for demonstration was the potential ability to protect workers from overexposure to air contaminants during torch cutting and air carbon-arc gouging of large and relatively immobile castings. Since the processes studied were manual operations, control of the process operator's exposure was the focal point of the selection process. However, the ability of a control measure to prevent contamination of the general background air was also considered to be of prime importance. Consideration was also given to, among other things, the amount of worker interaction required, compatibility with conventional material handling systems, worker safety, and energy requirements.

Process Changes

Exploring ways to reduce emissions or increase their controllability by changing the process and/or establishing operational parameters for the process was not incorporated into this demonstration project. These areas, which are subjects for continuing research and development, must be undertaken with production rate, cost, and the quality of the work as significant variables. For example, reducing the air flow rate of an air carbon-arc gouging tool would decrease the energy of dispersion of the air contaminants and probably increase their controllability. However, lesser quantities of air could potentially leave undesirable traces of carburized metal at the surface layer of the workpiece. Thus, any study assessing the feasibility of reducing air flow rate would need to evaluate surface carburization effects. The present study explored only add-on controls which did not impact on, nor interfere with, normal operation of the process to any significant degree.

Ventilation Approaches Selected

Past research on these processes has shown that localized exhaust hoods are effective in capturing air contaminants if the air jet from the tool, as it deflects off the workpiece, is directed at an exhaust opening. The larger and more immobile the casting, however, the more difficult this is to achieve. Compact, mobile hoods that the worker can reposition as required can increase the efficiency of direct capture, but these require very substantial worker awareness and interaction to be effective and are prone to fouling with slag. It was, therefore, decided to concentrate this project on "fixed" (immobile) ventilation methods. After evaluating various ventilation approaches, two different types were selected as suitable candidates for study:

1. Unilateral flow booths - Fully enclosing booths, either horizontal flow or downdraft, designed to create as uniform a velocity as possible within the entire confines of the booth.

2. Push pull tunnel - A partially enclosing method which employs directed air to push contaminants toward a receiving hood.

Unilateral Flow Booths--

Unilateral flow booths are subclassified as either vertical or horizontal flow booths. Examples of both are shown in Figure 6. The vertical booth shown is a downdraft booth; updraft booths, also in use in some industries, would not be feasible for these operations because the supply air would get contaminated with particulate matter as it blew through the pit area, which is open to substantial amounts of falling debris from the process.

There are two important control velocities associated with unidirectional flow booths that are independent of one another:

1. Uniform capture velocity throughout the booth.
2. Inlet velocity to prevent escape of contaminants from the booth, termed the retention velocity.

The capture velocity within the booth draws air contaminants away from the generation point and toward the exhaust point. It also helps to suppress fume rolling. It is produced by exhausting the booth with air that is equally distributed through the action of both supply-side and exhaust-side distribution panels.

The relationships between average unidirectional capture velocity within the booth, V_c, and the other pertinent ventilation parameters can be expressed as:

$$V_c = \frac{Q}{WH} \quad \text{(horizontal flow booth)}$$

$$V_c = \frac{Q}{WD} \quad \text{(downdraft booth)}$$

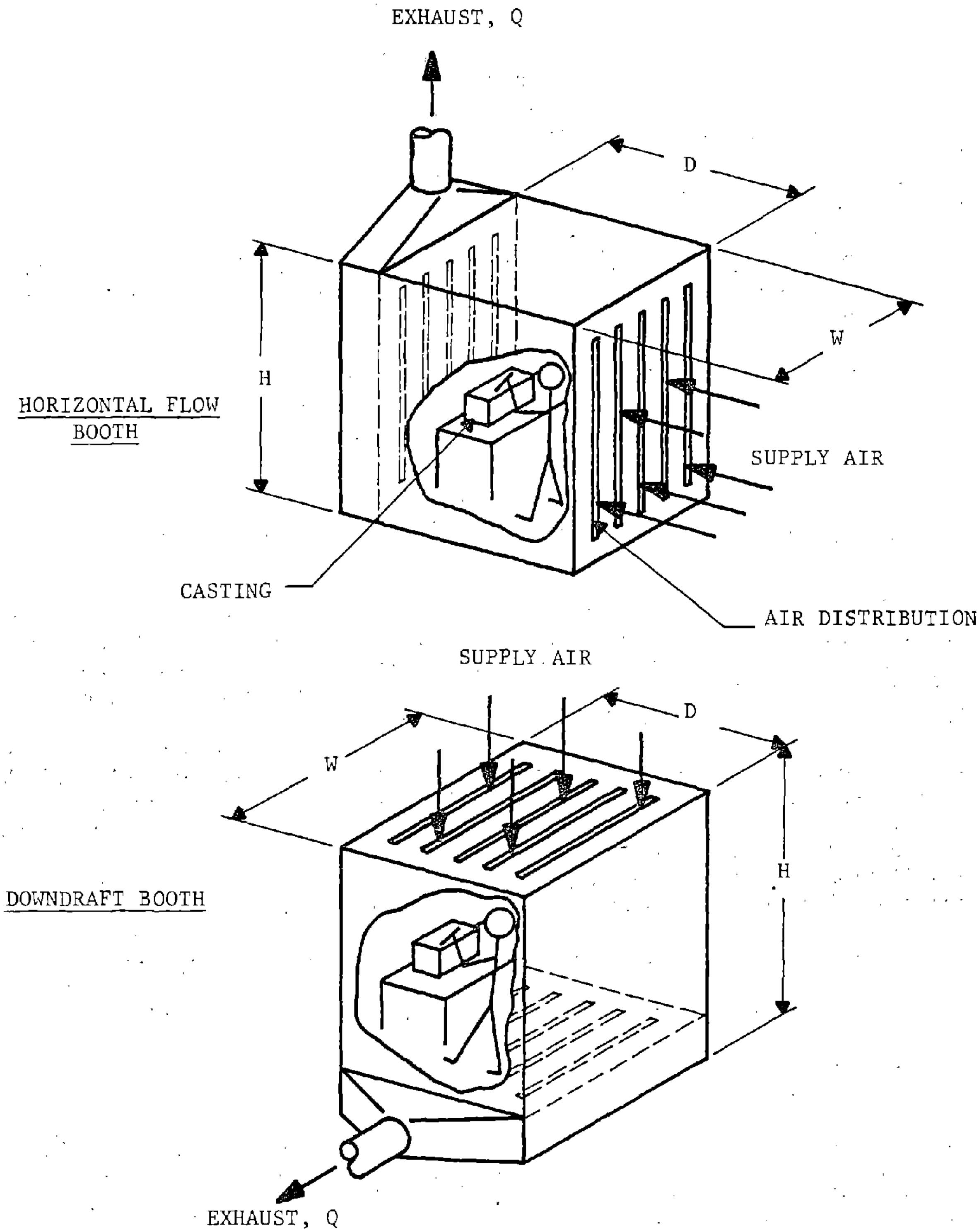


Figure 6. Simplified schematic of unidirectional booth approaches.

Where Q is the total exhaust rate and W, D, and H are the width, depth and height of the booth, respectively (see Figure 6).

It can be seen from these equations that, in the case of the horizontal flow booth, the relationship is independent of the depth of the booth, D; and in the case of the downdraft booth, it is independent of the height of the booth, H. This means, in effect, that the depth of a horizontal flow booth or the height of a downdraft booth may be shortened or lengthened without changing the basic velocity profile within the booth or increasing the required ventilation rate.

The retention velocity, V_r, prevents air contaminants from escaping the booth. The relationship between V_r and the other pertinent ventilation parameters can be expressed as:

$$V_r = \frac{Q}{WH\ (\%\ \text{open area})} \qquad \text{(horizontal flow booth)}$$

$$V_r = \frac{Q}{WD\ (\%\ \text{open area})} \qquad \text{(downdraft booth)}$$

Where % open area refers to the extent of open area in the supply air panel.

Unidirectional flow booths are sometimes improperly labeled laminar flow booths, however, their flow profile is far from being laminar in a fluid dynamic sense. Some air turbulence does exist, even in an empty booth. With the process in place and in operation, significant air turbulence is caused among other things, by the air nozzle on the tool, thermal convection from the process, as well as the imposition of worker, casting, and workbench into the flow stream. Depending on the configuration of the supply air grille, turbulence can also be created as the higher velocity supply air enters the lower velocity booth atmosphere. Direct evacuation of air contaminants as well as prevention of fume roll are keys to the ventilation design. These can be accomplished while minimizing but not necessarily eliminating air turbulence in the booth.

The three most significant factors affecting controllability are:

1. Direction of the air from the tool as it deflects off the workpiece.
2. Location of the worker.
3. Ventilation direction.

The primary rule for controllability is that the breathing zone should not penetrate the stream of air contaminants emitting from the process as the control velocity within the booth pushes them toward the exhaust point. One of the purposes in performing controlled experiments in this study was to examine how this can be effectively accomplished in a production environment. One fact was fairly obvious from the start. Keeping the worker upwind of the contaminants would be very impractical in a horizontal flow booth unless a turntable or other mobile method were provided for quick repositioning of the casting.

Supply air to the booth may be either drawn from the general building air or directly supplied by a fan through ductwork and a supply air plenum. Past experience has shown that, unless mechanically-supplied air is tempered during cold weather, supply air fans are usually shut off and their dampers are closed. Drawing air from the general building air, on the other hand, imposes the requirement that background air be free from significant contamination which could unnecessarily elevate the exposure of the worker in the booth. Since the booth is fully enclosed, supply air to the booth could be filtered, if necessary.

The features of the enclosed unilateral flow booth can be better appreciated when alternative approaches are considered. Following are descriptions of two alternative approaches used for processing of large workpieces in industry as well as critiques of their potential for air contaminant control.

Alternative 1 - Work Performed at a Booth Face

In this method, a booth is constructed with a front face which is partially open to allow sufficient accessability for a worker to process a casting whose work point is positioned at the face of the booth or slightly inside the booth (Figure 7). By keeping the worker outside the booth, the booth face plane is thus interposed between the air contaminant source and the worker's breathing zone, and the capture and retention velocities are identical. They can be expressed as:

$$V_c = V_r = \frac{Q}{A \times B - C}$$

Where A and B are the highest and width of the face area, respectively, and C is the vertical cross-sectional area of the casting at the face plane.

Since the goal of this method is to reduce exhaust rate, Q, by restricting the size of the face plane, the casting cross-section (as well as any casting support used) has a significant effect on capture velocity.

Note that the escape and capture velocities are independent of the overall dimensions of the booth, which can be built large enough to reduce splashback of air contaminants off the walls of the booth. In this method, the velocity profile inside the booth is inconsequential; the entire action of the control measure takes place at the face plane. This latter fact constitutes the inherent constraint of the method. Processing of large castings requires that work be performed at a variety of points around the workpiece and, unless repositioning is faithfully done, several problems can occur:

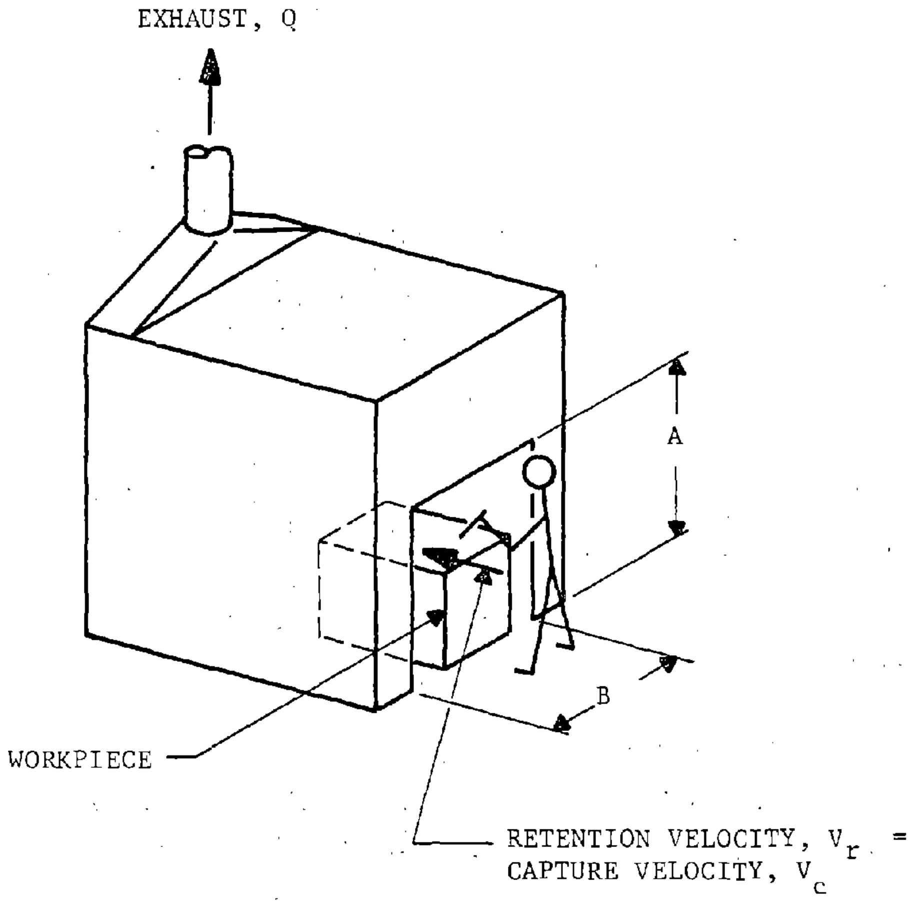


Figure 7. Simplified schematic of open faced booth approach used in industry.

1. The work point may be outside the face place. At small distances away from the face plane, capture velocity reduces dramatically. With increasing distance away from the face plane, capture effectiveness also becomes increasingly more dependent on the direction of the air flow from the nozzle.

2. The worker may enter the booth. At only small distances inside the booth, the worker is subject to exposure from freely rolling air contaminants.

This type of control measure, common in industry, is also used elsewhere in the cleaning room, where manual swing grinders are employed (5). Evaluation of its use has revealed that the tendency for the worker is to work outside the face of the booth. Unless special provisions are made to move castings into the face plane, such as the stationary turntable and retractable roof employed in a booth assessed in the NIOSH study (Figure 2), the workpiece is usually positioned outside the booth.

As stated above, capture velocity is increased and exhaust rate is decreased by reducing the size of the face opening to no more than is required to provide accessibility to perform the work. A severely restricted face plane, however, can pose a barrier to the worker to gain proper access to do the work.

Alternative 2 - "Air Sweep" Design in an Enclosed Booth

This booth is similar to the unilateral horizontal flow booth in that capture velocity, Vc, and retention velocity, V_r, are independent. The differences between the two methods are in the modes of supplying and exhausting air. Rather than uniform supply and exhaust air distribution across the front and back faces of the booth, air is introduced through a slot in the ceiling at the front of the booth and discharged through a slot in the lower back of the booth (Figure 8). This configuration results in the production of a strong mass of air sweeping down across the work from above and behind, creating a zone of significantly increased capture velocity, V_c. This is a very desirable aspect of this method, however, the benefits achieved are offset by a very defined drawback in that fume rolling is enhanced. As the high velocity stream of air moves through the booth from front to back, it creates an overhead eddy current which, in turn, transports some of the air contaminants generated by the process back toward the head end of the booth where they are entrained into the fast moving air stream. The pattern of this eddy current reinforces the fume roll created by the tool.

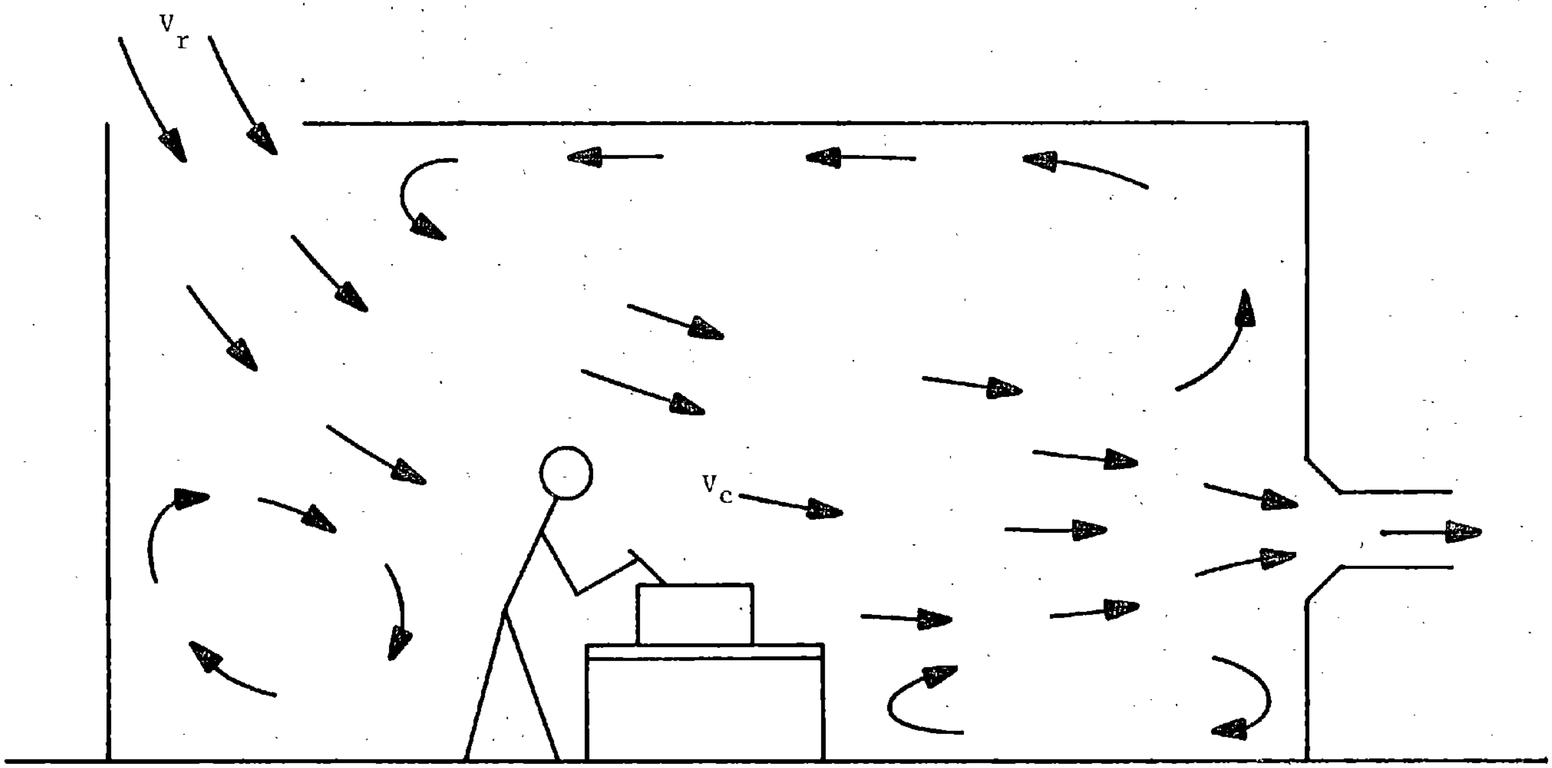


Figure 8. Simplified schematic of "air sweep" method used in industry.

Push-Pull Tunnel--

Although the "air sweep" design is not very adaptable to enclosed booths because it enhances the detrimental effects of fume roll, it is suitable as a semi-enclosed method with mechanically supplied air because, in this "push-pull" configuration, it does not produce fume roll. The method utilizes the ability of air to be blown for great distances while still maintaining a uniform and predictable flow pattern. The exhaust hood in the case of "push-pull" acts as a receiving hood, i.e., the contaminated air is propelled toward the capture hood by some force besides the suction of the hood, in this case, the pressure of the supply air stream.

The Monitoring and Control Research Branch of NIOSH's Division of Physical Sciences and Engineering has an industrial ventilation research program underway to develop the "push-pull" method as a viable industrial ventilation technique. Prior to the demonstration of "push-pull" ventilation in this study, NIOSH personnel set up a "push-pull" tunnel in their laboratory and developed parameters for a full scale demonstration in this study. The configuration indicated by the NIOSH development program is shown in the side view in Figure 9, with the ventilation patterns depicted. Two air nozzles are employed in the form of long slits, as wide as the walls in which the process is contained. The nozzle behind the worker is termed the main push-jet. This nozzle provides the primary force necessary to push air contaminants away from the work point and toward the exhaust point. The nozzle overhead is a secondary nozzle, termed the roof jet, which maintains sufficient velocity at higher levels between the work point and the receiving exhaust hood to prevent fume escape in this zone.

After emitting from the nozzles, the air jets immediately entrain surrounding air into an ever expanding, wedge-shaped air mass which sweeps past the work point. By the time this air mass reaches the receiving hood it has expanded to be at least ten times greater than the nozzle air flow. The exhaust hood must be sized to receive the entire amount of the moving air mass or fume will sweep on past the hood.

Prior to demonstrating this method on actual foundry production, smoke bomb tests were conducted in the assembled tunnel to visually verify that the foundry test installation reproduced the general flow/velocity relationships attained at the NIOSH laboratory.

AIR SAMPLING APPROACH

Air Contaminants Measured

The primary contaminants of hygienic concern in this particular foundry operation were the metal fume constituents, especially iron and copper. Iron, the principal constituent of steel, was present in castings at percentages which were orders of magnitude higher than any other element. Copper fume emits principally from the electrode sheathing which is consumed in the air carbon-arc process; copper was present at only trace levels in the castings themselves. Other casting constituents of hygienic

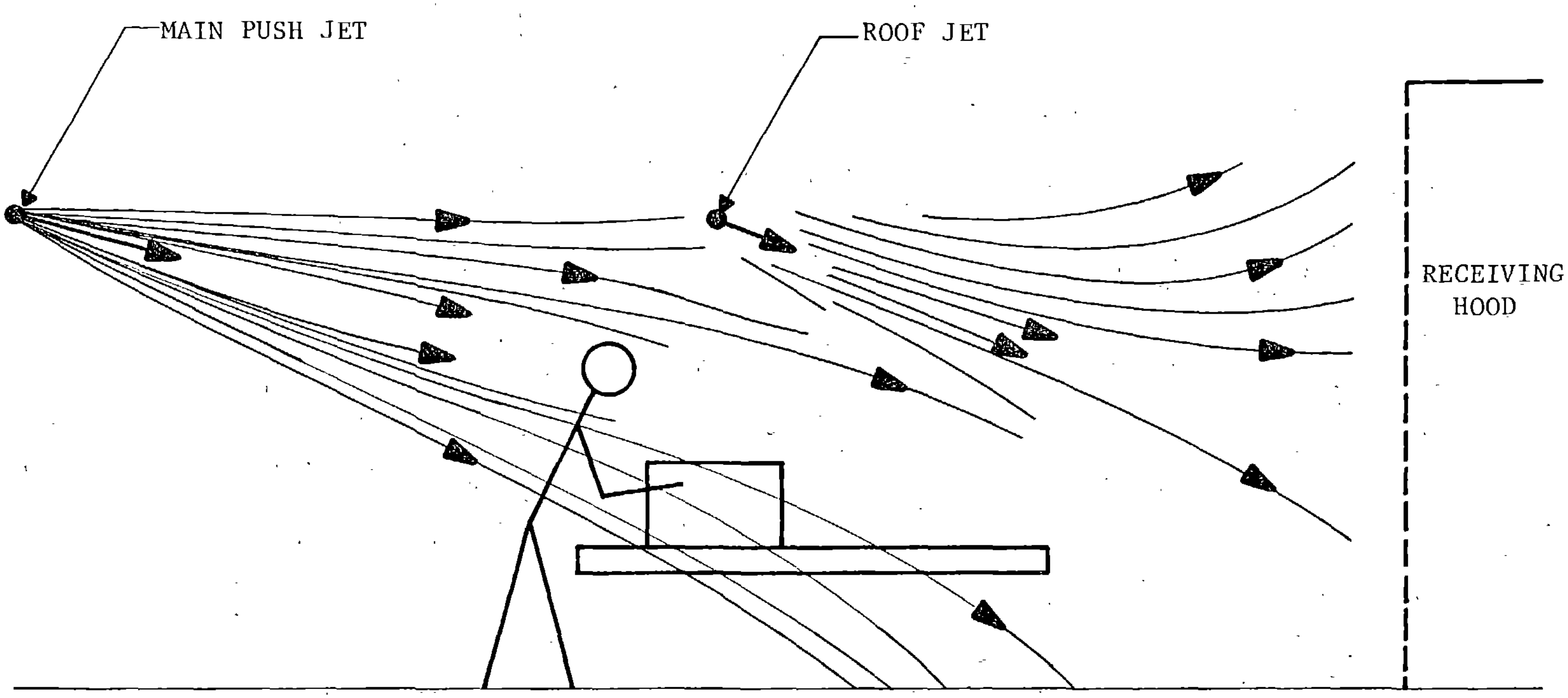


Figure 9. Ventilation patterns associated with push-pull tunnel.

concern which were actively controlled in the casting metallurgy included nickel, chromium and manganese. Lead was also included among the metals sampled because it was a "tramp" element in both the castings and electrode sheathings and because it had such a low Permissable Exposure Limit (50 μg/m^3).

All of the castings were shot blasted prior to torch cutting and gouging. Imbedded sand, however, is often not removed by blasting and thus crystalline silica was added to the list of contaminants of hygienic concern for measurement in this study.

Two other contaminants generated by air carbon-arc gouging, ozone and carbon monoxide, were not monitored because of previous findings which linked overexposure of these contaminants only to conditions of grossly inadequate ventilation at which iron and copper greatly exceeded permissable exposure limits (3). Thus, control of iron and copper were used in this study as indicators of control of these gases. To prevent cross-contamination from other airborne contaminant producing sources in foundry cleaning and finishing areas, air sampling data were gathered on an off-shift when activity in the foundry was limited to the processes being tested.

Air Sampling Method

Although the classical gravimetric method, i.e. drawing air through filters which are pre-and post-weighed, is satisfactory for assessing exposure to particulate emissions throughout workshifts, this method can be, by itself, quite unsatisfactory as an engineering tool in studies which attempt to evaluate and/or optimize engineering control measures. Where measurement of exposure levels resulting from specific tasks of an operation or specific ventilation conditions are desired, only short periods (perhaps minutes) at that condition are all that is often necessary to provide a valid sampling of typical exposures. The gravimetric method, however, may require hours before sufficient sample is gathered for valid readings to be taken. The more effective the level of control, the more encumbering the gravimetric method becomes.

Real time measurement methods are the key for data gathering of this type. In this study, a real-time monitor manufactured by GCA Corp., called RAM-1, was employed. With this device, aerosol concentration was sensed using a method based on the detection of near-forward scattered light in the near-infrared region. A recent NIOSH study found the RAM to be accurate within ± 10 percent over a test range up to 5 mg/m^3 when sampling welding fume (15). In that study, this instrument was also found to have minimal zero drift, the response time was rapid, and the unit performed reliably. The application of the RAM to the NIOSH welding fume study was different from the present application in that, in the former study, the device had to measure very low levels of contamination, at the outlet of air cleaners often in the microgram per cubic meter range. In the present study, exposures were expected to vary in the milligram-per-cubic-meter range from low values to perhaps 100 mg/m^3 or more. The range of the RAM extended to 200 mg/m^3. Filter sampling was performed side-by-side with the real-time sampling to calibrate the RAM and permit analysis of the levels of specific contaminants.

STUDY METHODS

In this section details are presented concerning the test booths and the measurement and analytical methods used in the study.

PILOT UNILATERAL FLOW TEST BOOTHS

Downdraft Booth

The test foundry already had a downdraft booth, but modifications were needed to accommodate a unilateral flow approach. The downflow exhaust grille in the existing booth did not cover the entire floor area, thus sheet metal walls were erected within that booth to create a new, smaller booth whose entire floor consisted of downdraft grating (Figure 10). The inside dimensions of the downdraft booth were 295 cm (116 in.) wide x 411 cm (162 in.) long x 304 cm (120 in.) high.

Castings were pushed into the booth on a rectangular cart on tracks (Figure 10). The cart had been designed with as much open area as possible to reduce interference to the downdraft air pattern. Figure 11 shows the downdraft booth with the doors closed during the operation.

The top of the booth was covered with grating. Twenty centimeters (8 in.) above the grating, wooden boards were used to close off sufficient roof area to provide a supply air velocity (termed retention velocity) that was three times higher than the unidirectional velocity (termed capture velocity) within the booth. Experiments showed that a 3:1 ratio between retention velocity and capture velocity would prevent any fume from escaping the booth within the range of the capture velocities tested [0.5-1.0 m/sec (100-200 ft/min)]. Roof boards were uniformly spaced for good supply air distribution to the entire roof area.

After the booth was constructed, velocity profiles were measured and it was found that downdraft velocities were much higher on the far end of the booth than they were near the door due to the exhaust takeoff being located on the far end of the pit. Sheet metal baffles were then placed in the pit area with spaces between them to balance the air flow and permit uniform downdraft velocities throughout the booth (Figure 12).

Air flow distribution within the booth was measured with an Alnor® Thermoanemometer throughout the range of velocities tested. A typical velocity profile is shown in Figure 13. The velocity pattern was quite consistent throughout the booth; only two small stagnation zones existed close to the two corners at the end farthest from the exhaust. Total air flow rate was measured using a pilot tube in the exhaust

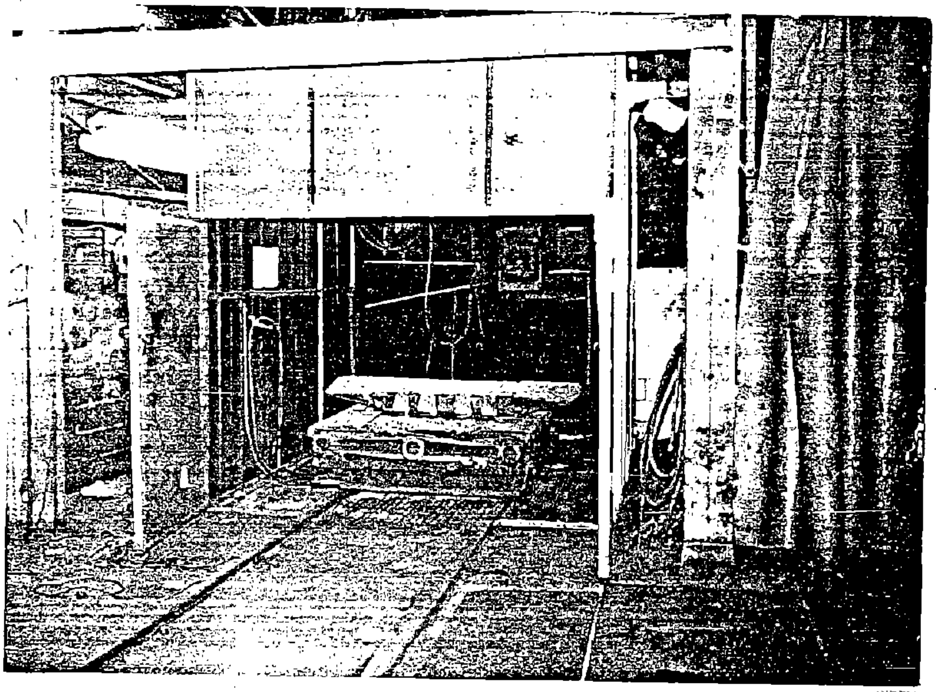


Figure 10. Unilateral flow downdraft test booth with the cart and workpiece in position for air carbon-arc gouging. Front swinging doors are closed during the operation.

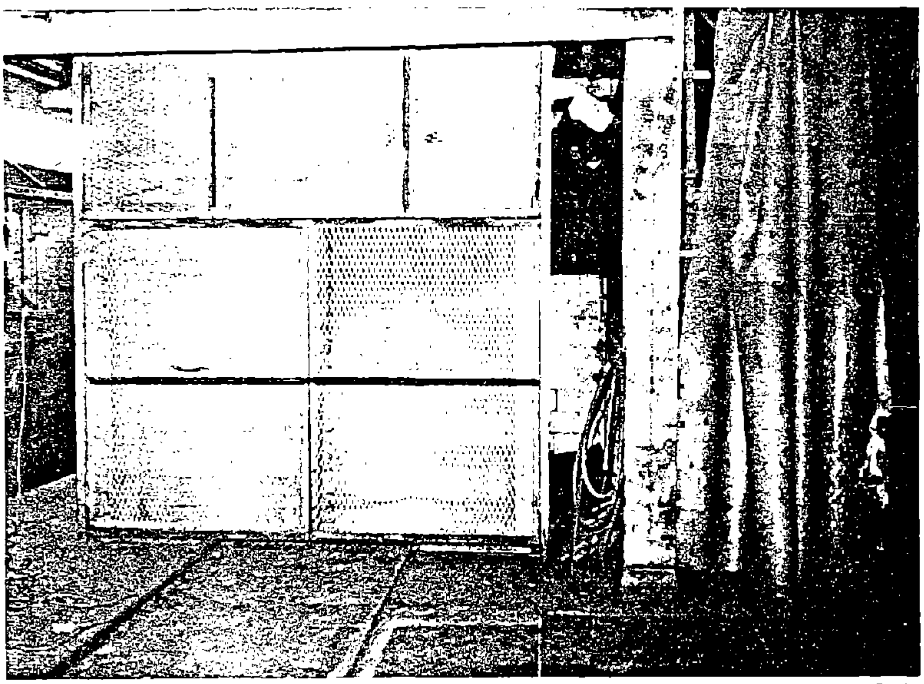


Figure 11. Unilateral flow downdraft test booth during operation.

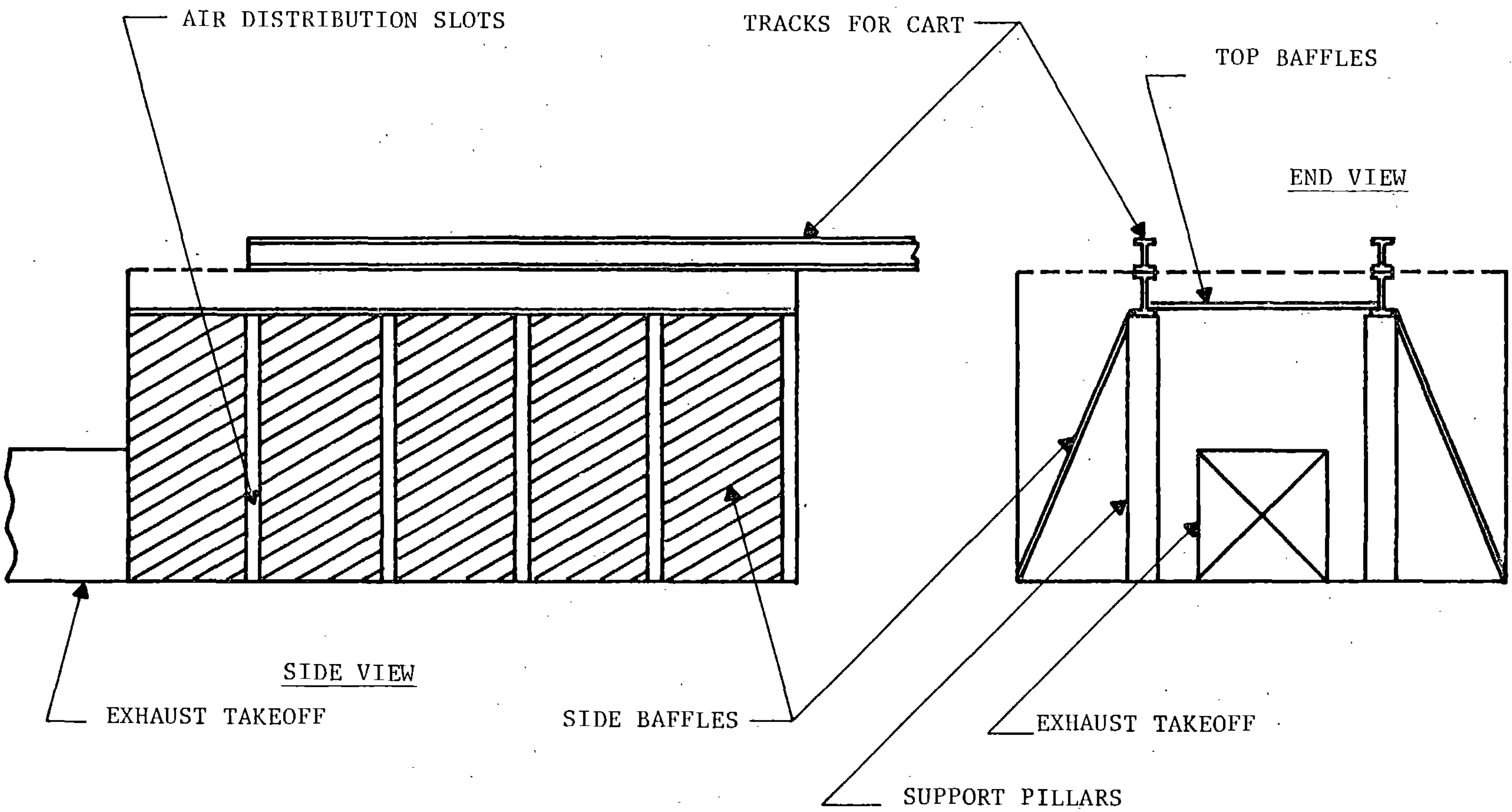
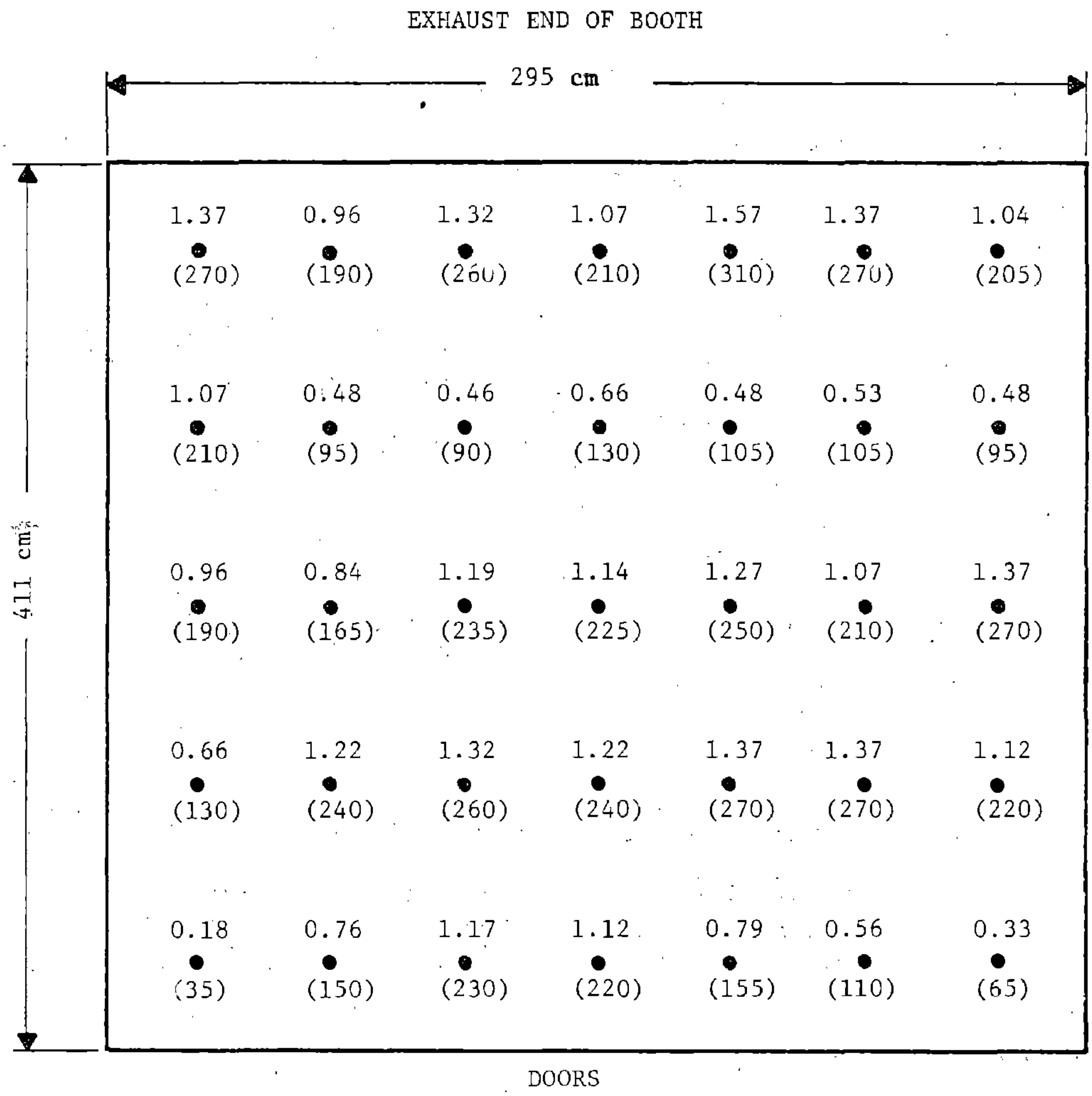


Figure 12. Schematic diagram of downdraft test booth pit.



AVERAGE VELOCITY 0.97 m/sec (191 ft/min)

VELOCITY RANGE 0.18-1.37 m/sec (35-270 ft/min)

FLOW CROSS-SECTION 295 cm wide x 411 cm long (116 in. x 162 in.)

TOTAL FLOW RATE 11.8 m^3/sec (24,900 ft^3/min)

Figure 13. Typical downdraft unilateral flow velocity profile-horizontal plane, at 152 cm (60 in.) height.

ductwork for each flow condition tested.

Horizontal Flow Booth

The horizontal flow configuration was constructed after completion of the downdraft test program through the following modifications to the downdraft booth (Figures 14 and 15):

1. Covering of the floor.
2. Erection of a sidedraft distribution panel (30 percent open area).
3. Blanking off of the roof.
4. Extension of the booth on the door end and removal of the sheet metal over the grating on that end.
5. Installing supply air inlet distribution boards.

For the horizontal flow tests, the rectangular casting cart was replaced by a cart with a manual turntable on it (Figure 15).

Balancing of flows was performed by blanking off portions of the lower slots in the distribution panel. Velocity patterns within the horizontal flow booth were also consistent, with only two small stagnation zones in the upper corners along the sidewalls (Figure 16).

Hood Static Pressure

Static pressure measurements, taken in the outlet duct from the booth, were approximately the same for backdraft and horizontal booths.

Booth ventilation rate		Hood static pressure,	Entry loss, *
m^3/sec	ft^3/min	inches H_2O	inches H_2O
5	10,600	0.52	0.34
6	12,700	0.68	0.43
7	14,800	0.90	0.54
8	17,000	1.20	0.75
9	19,000	1.45	0.89
10	21,200	1.75	1.02

*Hood static pressure minus the velocity pressure in the duct.

PUSH-PULL TUNNEL

The push-pull tunnel was constructed after completion of the horizontal flow booth test program by adding the following components and using the booth as a receiving hood:

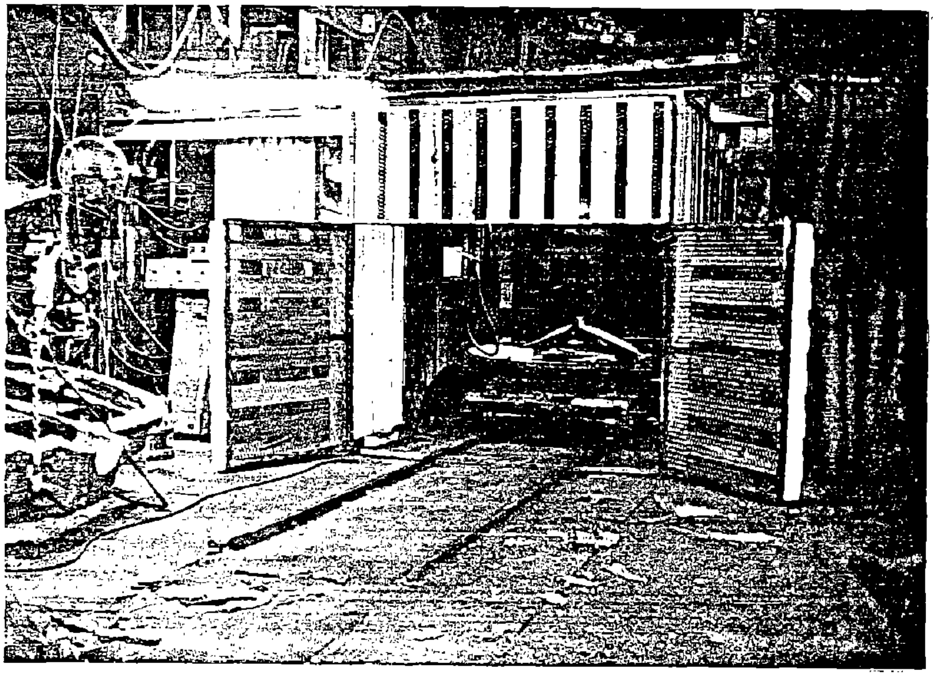


Figure 14. Unilateral horizontal flow booth with the turntable and workpiece in position for air carbon-arc gouging. Front swinging doors are closed during the operation.

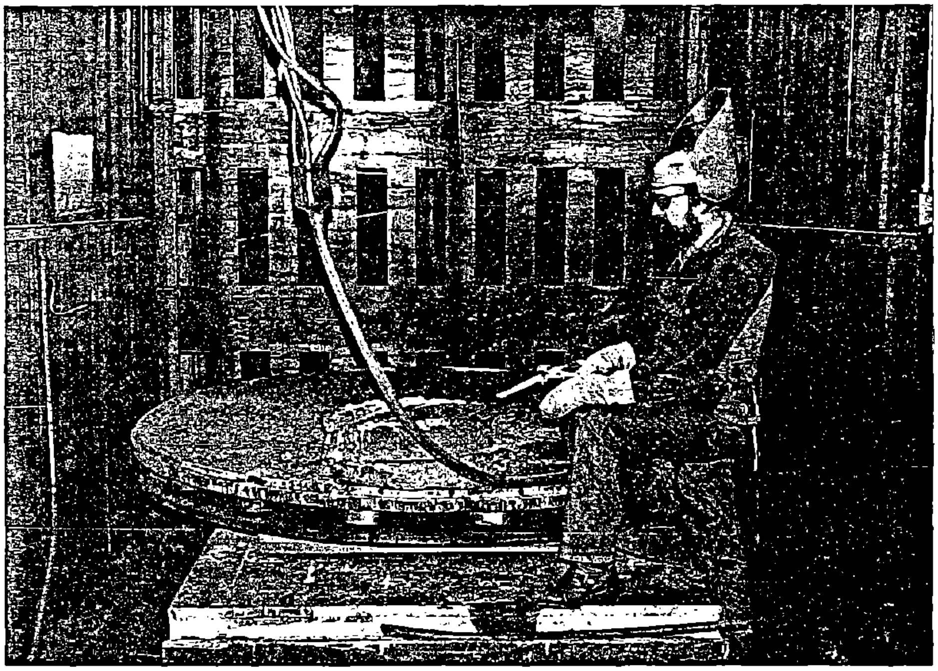
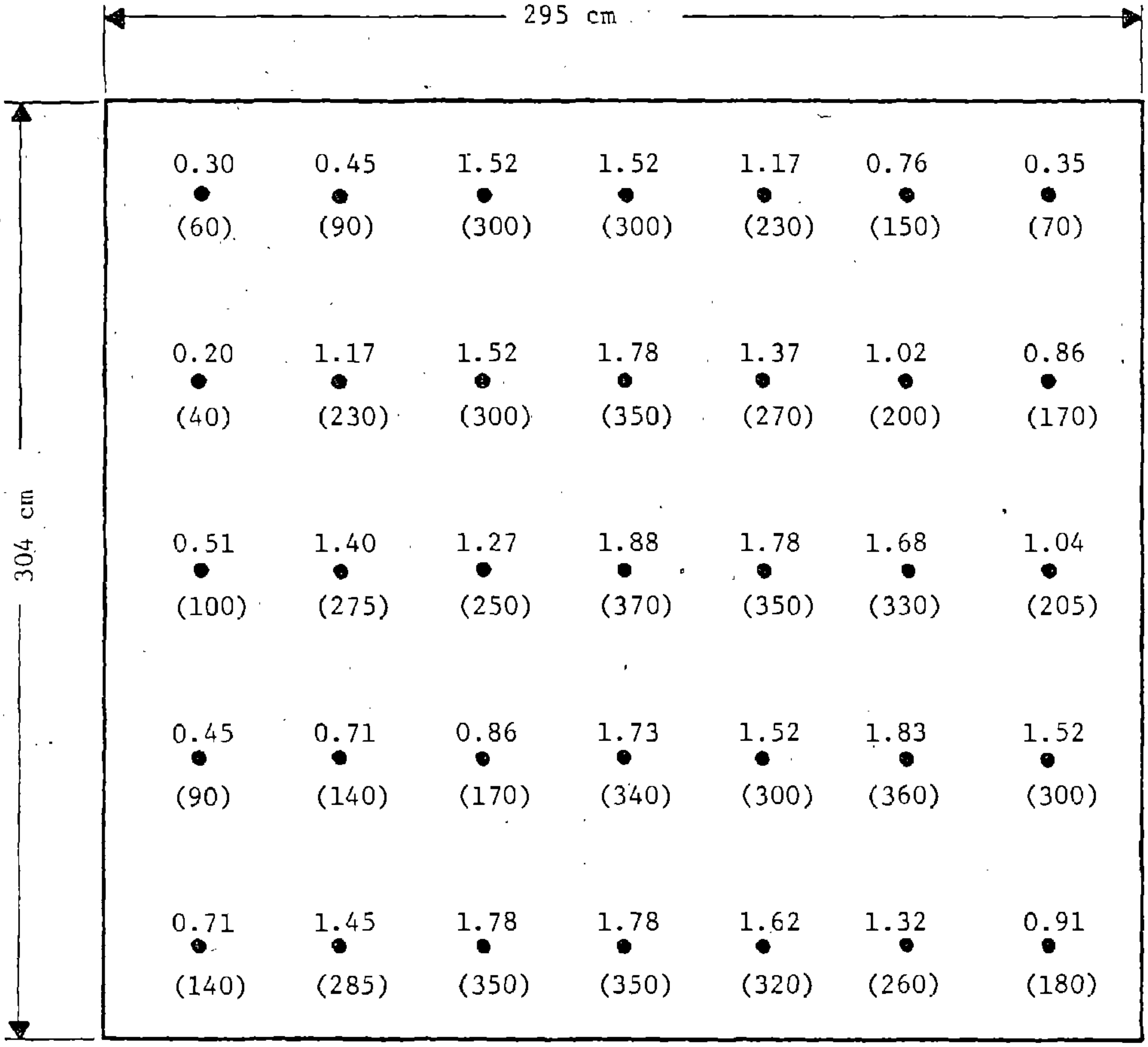


Figure 15. Inside of the unilateral horizontal flow booth with the worker positioned for side ventilation. Exhaust distribution panel is in the background.



AVERAGE VELOCITY 1.19 m/sec (235 ft/min)

VELOCITY RANGE 0.30-1.88 m/sec (60-370 ft/min)

FLOW CROSS-SECTION 295 cm wide x 304 cm high (116 in. x 120 in.)

TOTAL FLOW RATE 10.7 m^3/sec (22,700 ft^3/min)

Figure 16. Typical unilateral horizontal flow velocity profile-vertical plane, 45 cm (18 in.) inside of booth, upstream of worker.

1. Two-2.44m (8 ft) high x 9.15 m (30 ft) long walls consisting of welding curtain on a wooden frame were erected, extending outward from the unilateral horizontal flow booth to form a 3.05 m (10 ft) wide tunnel (Figure 17). Sheet metal inside liners were used in the work zone to prevent the weld splatter from contacting the curtains.

2. Two slit nozzles were constructed (Figure 18) and mounted behind and above the worker to create a main pushjet and a roof jet.

3. A blower was installed outside the booth and ducted to both of the nozzles (Figure 17). Blast gate dampers in the branch lines to the nozzles were used to adjust flows which were measured in the branch lines with a pitot tube.

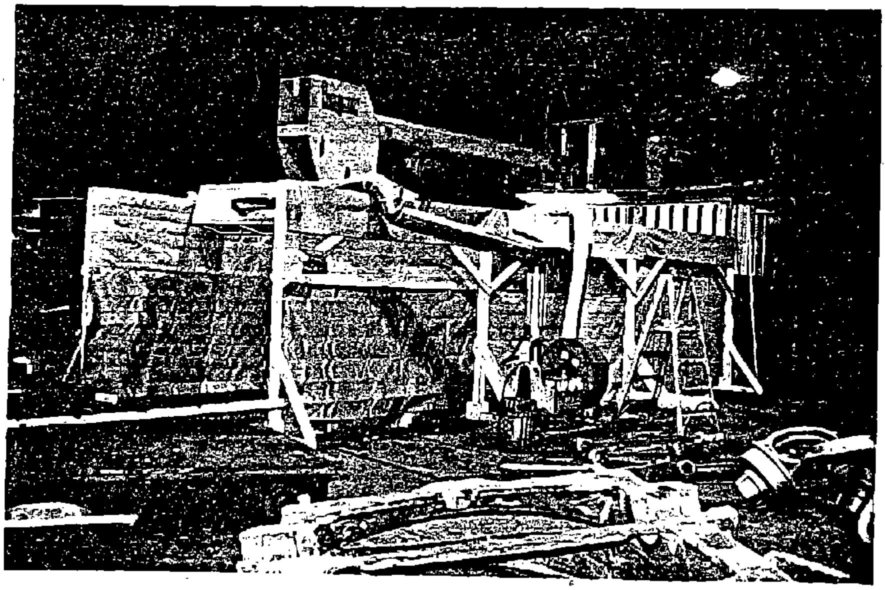
4. The turntable was removed from the inside of the unilateral flow booth and installed within the tunnel (Figure 17).

The air flow and dimensional parameters of the booth are shown in Figure 19 and the measured velocity profile in the booth is shown in Figure 20.

AIR SAMPLING METHODS

Real-time samples were withdrawn from under the welding helmet along with side-by-side filter samples, (37 mm, 0.8 μ pore size, PVC) both at the rate of 2 l/min (Figure 21). In-helmet sampling inlets were fastened to a bracket which attached to the headband of the helmet to keep them in a fixed position within the breathing zone. Space limitations within the helmet required the use of a filter cassette with a side port and the only one found to be commercially available (Casella® filter holders) was an open-faced cassette, not the closed-face cassette typically used in this type of sampling. The open-faced cassette was ultimately used because past research has shown that there is no significant difference in pickup of particulate between open and closed face cassettes when metal fume is being sampled (17). The real time sample was also withdrawn through an open-faced filter cassette, but without a filter attached. Filter samples were also gathered simultaneously on the worker's lapel. DuPont® Model P-2500 constant flow sampling pumps were employed for filter sampling and were mounted on the worker's waist. Rotameter checks of the flow rates were made at the beginning and end of each sampling period.

The real-time air sample was transported to the (RAM) monitor located outside the booth using 12 m (40 ft) of Tygon® tubing of 64 mm (0.25 inch) inside diameter, inserted inside a braided air pressure hose for protection against kinking or pinching off. The RAM flow rate and strip chart recording of the RAM output were continuously monitored throughout the tests by a study team member stationed at a window through which he could observe the process (Figure 22).



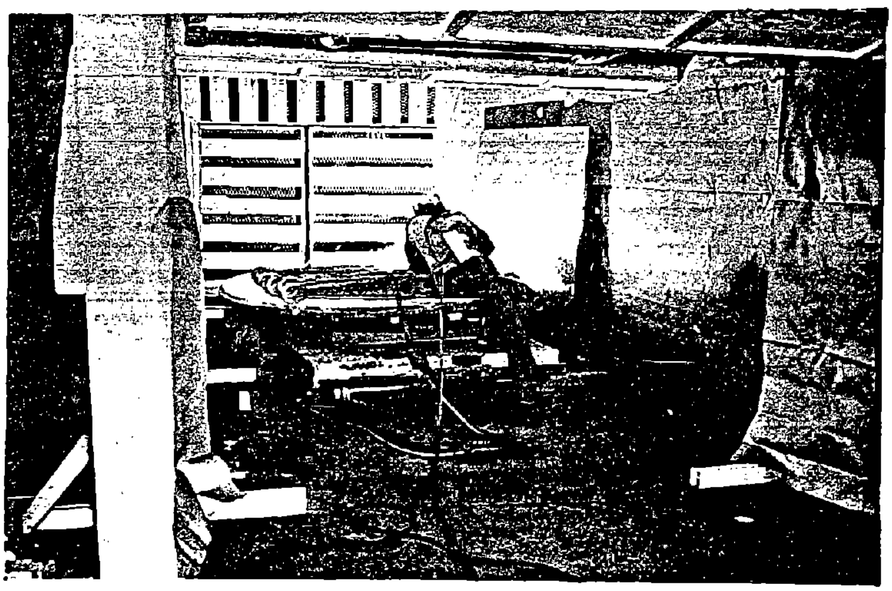


Figure 17. "Push-pull" tunnel in operation as seen from the side (upper photo) and open end (lower photo).

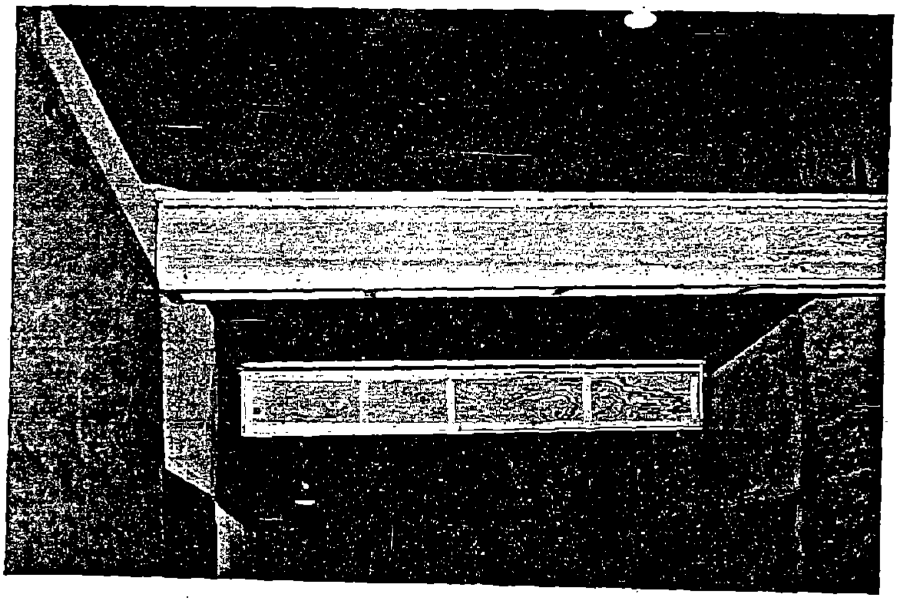


Figure 18. Slit nozzles for "push-pull" tunnel as seen looking down the tunnel from the exhaust end.

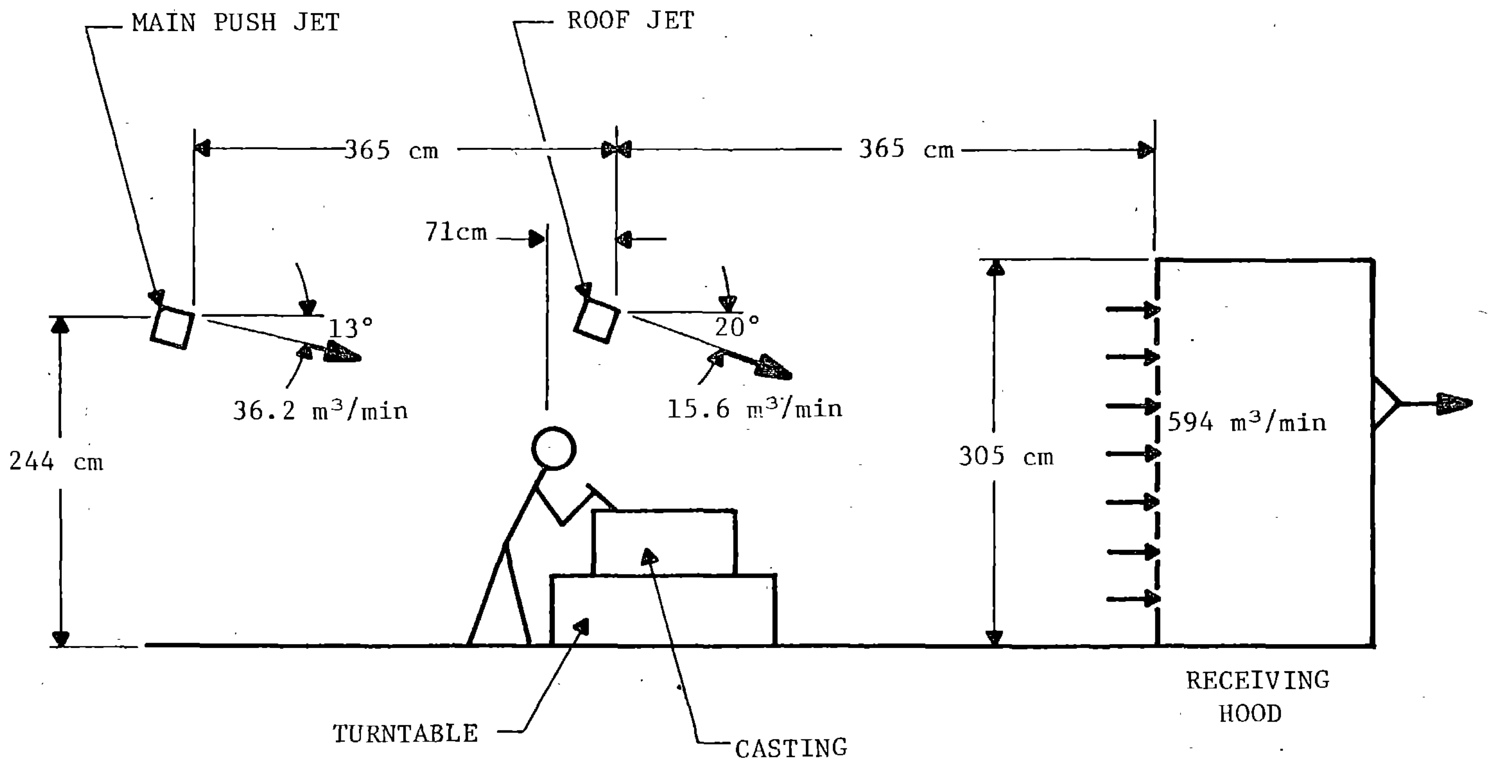


Figure 19. Schematic diagram of dimensions and air flow rates- "push-pull" tunnel test arrangement.

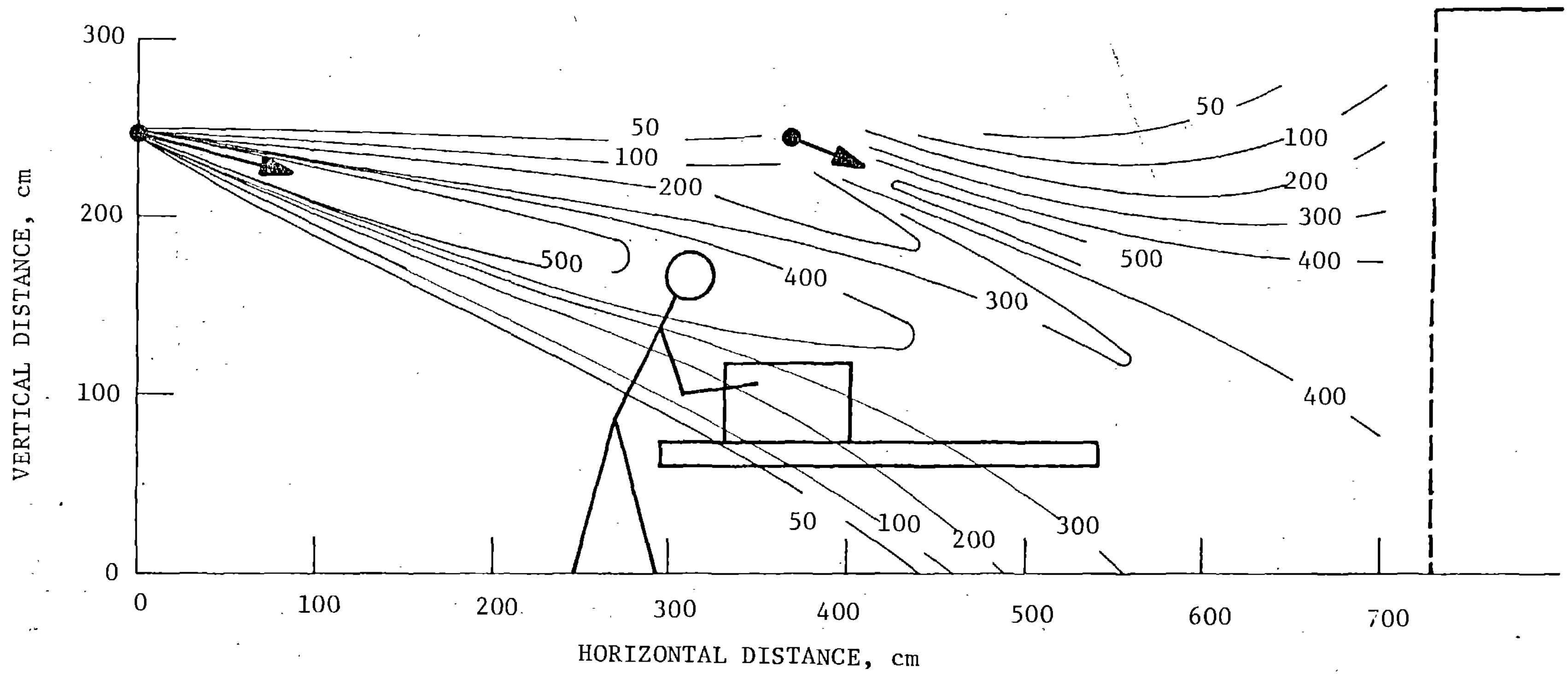


Figure 20. Velocity patterns - "push-pull" tunnel.

Figure 21. Air sampling devices being mounted on the air carbon-arc gouging operator. Sampling inlets inside the helmet were attached to a bracket which was mounted on the head band of the helmet; an additional filter cassette was mounted on the worker's lapel.

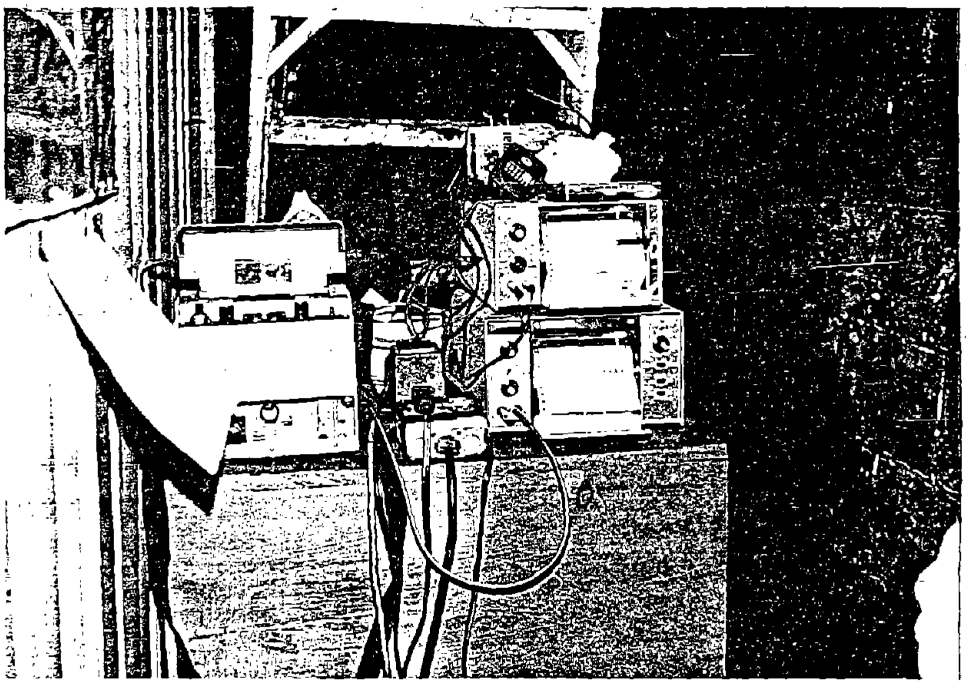


Figure 22. Monitoring station at unilateral flow booth window. On left is the real-time aerosol monitor (RAM-1). On the right are recorders for the RAM measurement and arc time.

Measurement of Exposures from Real Time Data

The desired sampling times for exposure evaluation at the various test conditions were in the range of 10-20 minutes, whereas one or more hours were necessary to gather sufficient sample on a filter for gravimetric analysis. Therefore, the first step in calibrating the RAM was to integrate the strip chart analog reading during the entire period of the gravimetric sample. This calibration could then be applied to any test interval within this period. Integrations were performed using a Hewlett-Packard 9872C Plotter as an analog-digital converter, feeding a Hewlett-Packard 9845 Desk Top Computer.

The relationship between the integral of the real-time aerosol monitor chart and the mass of particles collected on filters was found during the study to be consistent throughout the range of concentrations tested and did not change with the length of time that the sample line was in service. The close correlation between visual observations of the fume and measured concentrations lent further credibility to the sampling method. At the very end of the study, a prototype of a new RAM device, which can be mounted on the worker's body, called the Mini-RAM®, was made available by GCA Corp. to the study team for a brief demonstration which showed that the patterns of exposure were similar between this device and the large RAM monitor which received its aerosol through the long tube.

No attempts were made to perform an assessment of peak exposures occurring during the test program because of the possibility for dampening of these peaks as the aerosol flowed through the long tube. Rather, the analysis was limited to determination of time-weighted averages based on the integration of the RAM charts.

Analysis of Filter Samples

A sodium peroxide fusion method was employed to digest the PVC filter pads. This method dissolves the various refractory nickel oxides associated with hot processes better than nitric acid. Following is a summary of steps in the method:

1. Carefully transfer the PVC filter from the cassette to a clean watch glass.

2. Wet the filter with one drop of distilled, deionized water.

3. Sprinkle about 30 mg Na_2CO_3 onto the membrane filter.

4. Carefully fold the filter with the help of two pairs of tweezers and place it in a 10 ml capacity zirconium crucible.

5. Dry the sample at 105°C on Bunsen burner.

6. Ignite the filter at 500°C on Bunsen burner.

7. Cool, add 300 to 400 mg of Na_2O_2 and fuse the sample at 750 to 800°C.

8. Cool, add 5 ml distilled, deionized water to the sample, warm to leach all the Na_2O_2 salt.

9. Cool, carefully acidify the sample with 1 ml HNO_3.

10. Transfer the sample into the 10 ml volumetric flask, dilute to mark with distilled, deionized water.

11. Analyze by Atomic Absorption Spectrophotometry.

TEST RESULTS

TEST CONDITIONS

Air Carbon-Arc Gouging

Two different combinations of electrode size and current were used, resulting in two different rates of fume production:

High production: 1.90 cm (0.75 in.) diameter electrode at 1250-1600 amps DC

Low production: 1.27 cm (0.50 in.) diameter electrode at 800-1000 amps DC

The electrodes used were manufactured by Ibigawa and the predominant electrode holder used was an Arcair® Model K-6, which supplied 0.017-0.019 m^3/sec (36-41 ft^3/min) of air at 5.6 g/cm^2 (80 lb/in^2). Selected tests using the larger diameter electrode also employed the Arcair Tri-Arc® electrode holder. The electrode received its electrical power from a Miller Welder Model SR-1500-A1 (Miller Electronics). Percent arc time of total work time during the tests (measured electronically) ranged from 40 to 96 percent.

Oxy-Fuel Torch Cutting

The cutting torch was a Smith Model SC-72-L which burned Flamex®, a fuel composed of 90 percent propane with additives to slow down but intensify the burning. The gauge pressures were 11.2 Kg/cm^2 (160 lb/in^2) oxygen and 1.4-1.6 Kg/cm^2 (20-23 lb/in^2) Flamex®. Pressures at the tool were estimated to be 5.2 and 1.2 Kg/cm^2 (70 and 16 lb/in^2), respectively.

Castings Processed

The majority of tests run were on normal foundry production. Scrap castings were also employed in special tests to further evaluate certain parameters. Following is a typical metallurgical composition (besides the iron base) for the castings:

Elements actively controlled by the melting practice, %

C	Mn	S	P	Si	Ni	Cr	Mo
0.20	0.17	0.02	0.02	0.07	0.54	0.32	0.18

Residual trace elements (not intentionally added)

V	Al	B	Cu	Zr	Ti	Pb
0.004/0.022	0.010/0.099	0.0001/0.0006	0.06/0.17	<0.001	<0.002	0.001/0.004

Workers Employed

Only experienced air carbon-arc gouging and torch cutting operators were used. All of the torch cutting was performed by a single individual; most of the air carbon-arc gouging was also performed by a single individual. A second worker performed some of the air carbon-arc gouging work. Work practices were consistent between these two air carbon-arc gouging operators and did not appear to be a significant factor affecting the results. Respirators were provided by the foundry (standard operating practice) and were often in use by the workers.

Foundry Conditions

The tests were conducted during an off-shift to prevent cross-contamination of air contaminants from other processes. They were run between September and December, 1982. Background contaminant levels were very low and were subtracted from the personal sampling results. Since the booth exhaust was discharged outdoors, worker exposure returned to consistently low levels after each test period.

CHEMICAL ANALYSIS OF AIR SAMPLES

Several in-helmet samples gathered during the study were analyzed for metals. Averages of these sampling data for each metal are presented in Table 2 as percentages of metal in the total particulate accumulated on the filter sample. These results are comparable to those obtained in another foundry in a previous study of these process operations on workpieces of similar metallurgy (5).

In the column heading on the far right side of the table,a total particulate concentration is presented above which that constituent would, on the average, exceed its exposure limit. Limiting concentrations were calculated by dividing the PEL for a particular metal by the average percentage of that metal measured. The sample size was certainly not large enough for this analysis to be considered precise, rather, it was intended to give a rough estimate of which metals should be keyed on from a health standpoint for these processes on this general class of metallurgical conditions. In the case of the air carbon-arc process, copper, as expected, was the target metal and it was associated with an exposure to total particulate of slightly under the inert or nuisance dust PEL of 15 mg/m^3. Overexposure to iron occurred at twice the inert or nuisance dust standard. With their present standards, nickel, chromium, lead and zinc were not potential problems. Because this study was not able to accurately quantify peak exposures, assessment of ceiling values for manganese was not attempted.

The oxy-fuel process, as expected, had a lower copper exposure and, thus, iron became the target metal, approaching twice the inert or nuisance dust standard. The above tests show that control to the inert or nuisance dust standard is a good general baseline for judging the effectiveness of ventilation measures for these processes and

TABLE 2. METAL CONSTITUENTS IN THE AIR SAMPLES

Metal	Percent of total particulate†				OSHA PEL,§ mg/m^3	Limiting exposure to total particulate, mg/m^3 χ	
	Air carbon-arc		Oxy-fuel cutting				
	This study	Ref. 5	This study	Ref. 5		Air carbon-arc	Oxy-fuel cutting
Iron	39.8	34.5	33.9	37.8	10	25.1	26.5
Copper	0.69	0.31	0.13	0.23	0.1	14.5	77.0
Chromium	0.09	0.29	0.08	0.13	1	1111	1250
Nickel	0.18	0.02	0.09	0.38	1	555	1111
Zinc	0.14	0.05	BDL	0.11	5	3571	-
Lead	BDL*	BDL	BDL	BDL	0.05	-	-
Manganese	0.81	0.97	0.66	0.29	5**	-	-
(no. of samples)	(4)	(28)	(1)	(3)			

† Based on geometric means of time-weighted average (TWA) air sampling data.

§ Permissible exposure limit.

χ Concentration of total particulate above which overexposure would occur to a particular metal; calculated by dividing the PEL by the percent of this metal present.

* Below detectable limits.

** Ceiling value, not evaluated in this study.

workpieces of this metallurgy.

Total crystalline silica analyses (6 samples) indicated less than 1 percent quartz in all cases. This was expected for several reasons: castings were shot blasted prior to processing, there were no sand pockets in the castings, and the floor was either grating (unilateral flow booths) or plate (push-pull tunnel) with no significant dust and sand buildup.

WORKER EXPOSURE DATA

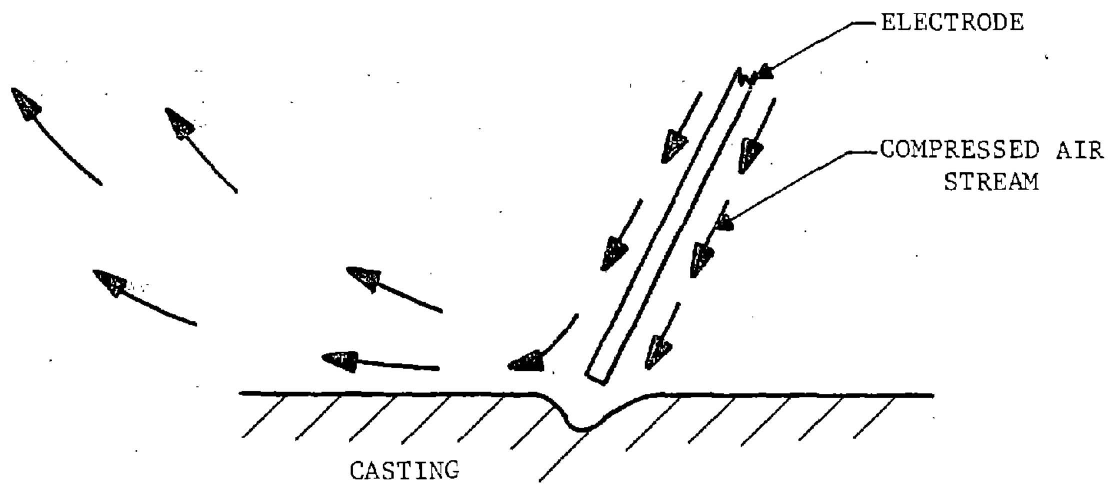
Unilateral Flow Booths

Air Carbon-Arc Process--

Some of the major factors investigated included type of task performed, body position assumed, production rate (in terms of both electrode size/ electrical current combinations and percent arc time) and ventilation rate. The parameter which had by far the greatest impact on exposure level was degree of confinement of the contact point between the electrode and the workpiece. This will be further illustrated with the help of Figure 23. When the contact point was on an exterior, fully exposed surface of the casting (upper sketch, Figure 23), the air jet from the tool dispersed the fume away from the work point, allowing the ventilation system to easily capture the contaminants, thus preventing fume rolling and contamination of the breathing zone. In this situation the air jet from the tool actually assisted the ventilation technique in that it tended to blow contaminants away from the immediate vicinity of the worker.

The principal problem with fume control occurred when other casting surfaces or the workbench constituted physical barriers to the free dispersion of the air jet (bottom sketch, Figure 23). Often these "interfering" surfaces redirected the force of the air jet back towards the worker ("splashback"). Since the worker's breathing zone was rarely more than a meter away from the work point, the booth ventilation system in this case could hardly prevent substantial penetration of fume into the breathing zone. Figure 24 shows a typical production casting requiring both exterior and confined work. The metal pad to be "arc washed" from the outside of this spool-shaped casting is a good example of exterior work with no physical barrier to dispersion of the air jet. The hub, however, on top of the casting was somewhat confined and "arc washing" of it resulted in rebounding of fume upward off the surrounding rim toward the breathing zone of the worker whose head was not far above the casting. The casting in Figure 25 illustrates a further complicating factor of some confined work which added to the fume generation rate. With this casting lying flat, three pads of metal were removed from a groove running completely around the casting. As these pads were melted away by the tool, molten metal accumulated in the groove. The contact of the air jet with this molten pool resulted in a dramatic rise in fume generation rate as the air jet oxidized at the surface of the molten metal pool. No such problem occurred while working on the hub in Figure 24 because, even

EXTERIOR GOUGING (NO FUME "BACKSPLASH")



CONFINED GOUGING (FUME "BACKSPLASH" AT THE WORKER)

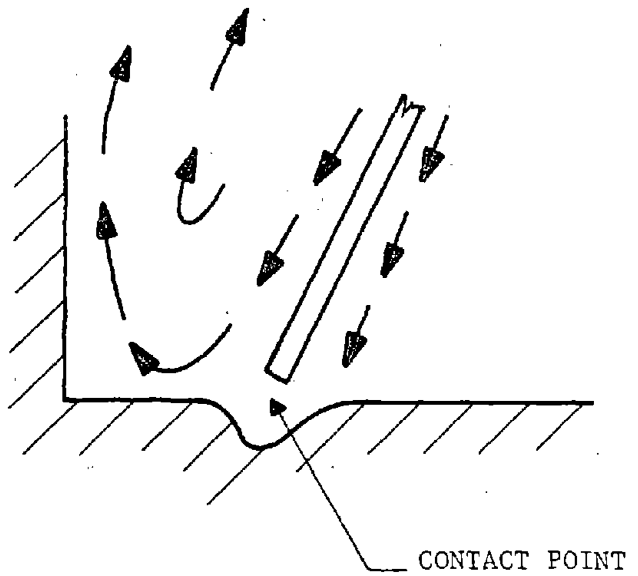
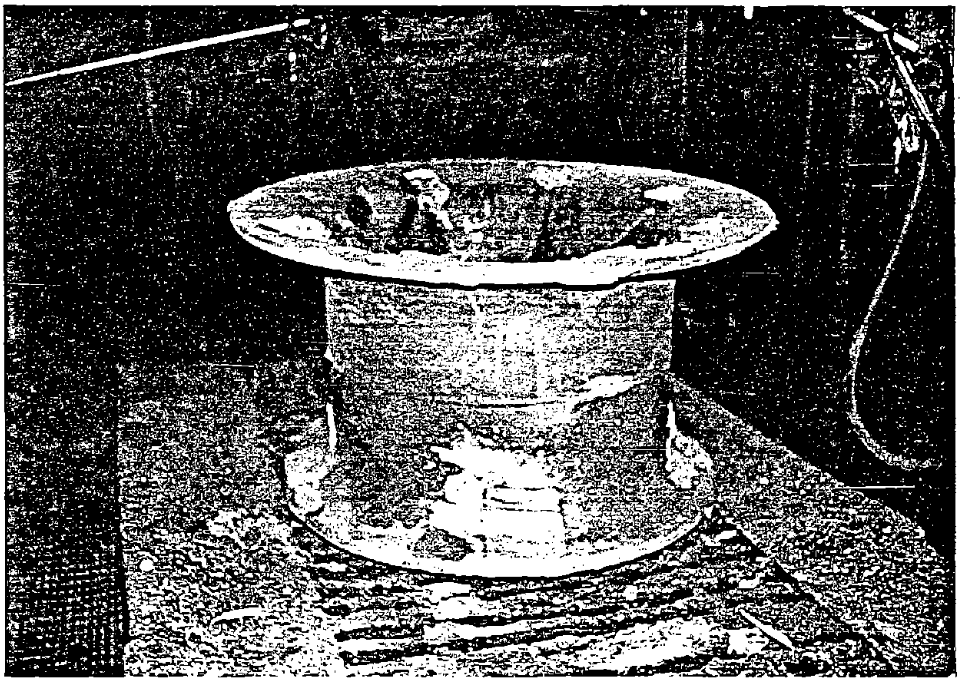


Figure 23. Schematic diagrams of the air carbon-arc process showing the action of casting surfaces nearby the contact point in redirecting the jet air stream back at the worker ("backsplash").



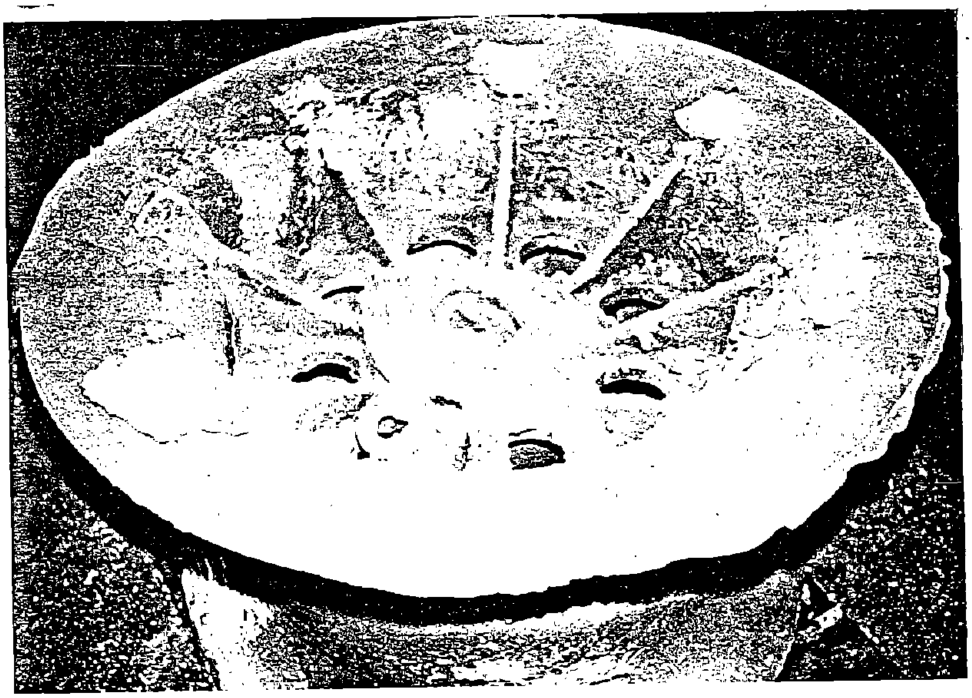
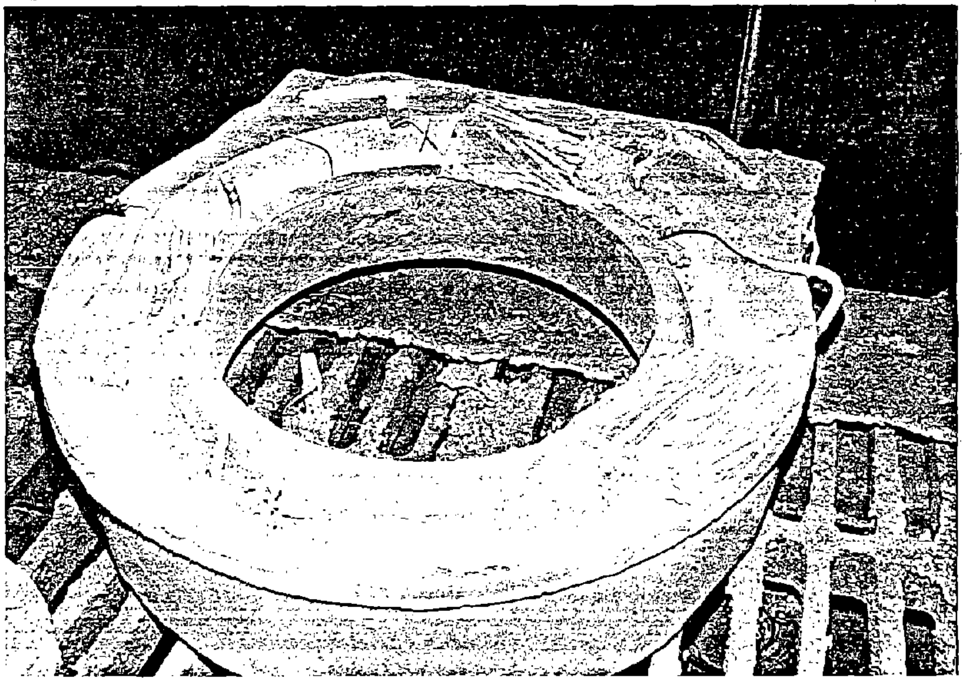


Figure 24. Fume controllability varied significantly between the open work on the lower outside of the casting (upper photo) and the semi-confined work on the hub on top of the casting (lower photo).



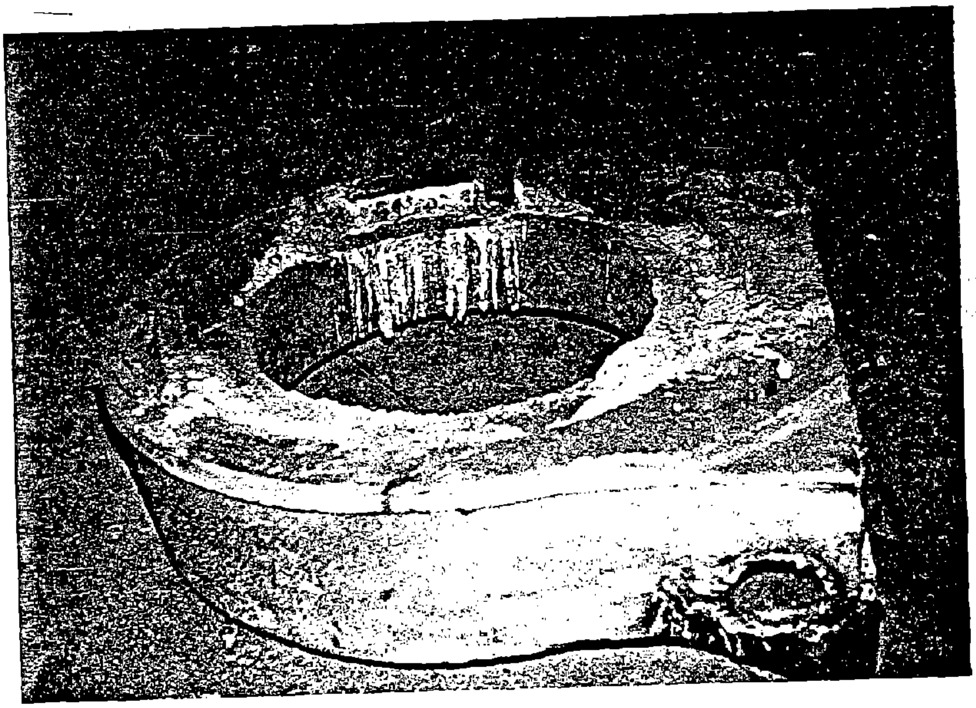


Figure 25. Fume generation rates increased significantly as molten metal pooled during "arc washing" of three areas within a groove (upper photo was taken prior to air carbon-arc gouging; lower photo after).

though the processed surface was flat, there was no reservoir in which the free flowing molten metal could collect.

Because of the predominance of the confinement factor on worker exposure, results of the production tests for both sidedraft and downdraft booths (Figures 26-27) are subdivided into the two classes of work. Later experiments were to demonstrate that there were degrees of confinement which resulted in varying amounts of "splashback". Based on the amount of "splashback" witnessed during normal production, this work was generally classified as "low to moderate confinement." The control line on these graphs represents the PEL for inert or nuisance dust (15 mg/m^3) at which the individual metal constituents of the fume were at or below their PEL's.

In the case of exterior work, worker exposure was not significantly affected by changes in either production rate or ventilation rate, within the range of conditions tested. Worker exposure was well-controlled in both downdraft and horizontal flow booths, with one exception. At the lowest ventilation rate tested (0.50 m/sec), the worker in the horizontal flow booth was slightly overexposed when he was standing sideways with respect to the direction of air flow. It was visually apparent that this ventilation rate was too low to prevent fume roll as the air jet hit the booth sidewall and rebounded back toward the worker.

Low to moderate degrees of confinement resulted in overexposure at the lower ventilation rates. Worker exposure was definitely production and ventilation rate-dependent.

In the case of the downdraft booth, a minimum of 0.75 m/sec (148 ft/min) was necessary to control worker exposure during confined low production work; higher production confined work required a minimum of 0.95 m/sec (187 ft/min) for control.

In the case of the horizontal flow booth, ventilation direction had a significant impact on worker exposure during confined work. With side ventilation, worker exposures for confined work were only 22-33% as high as exposures during ventilation from the back. This result was expected due to the barrier effect of the body and the eddy currents produced immediately downwind of the body. Above a minimum sidedraft ventilation rate of about 0.8 m/sec (157 ft/min) worker exposure during high production confined work was controlled to below the PEL when the ventilation direction was from the side. Within the range of unilateral flow velocities tested, worker exposure was never controlled when confined work was performed with the ventilation from the back.

Visual monitoring during confined work indicated that the quantity of the "splashback" varied significantly, increasing as the deflecting barriers became larger or were located closer to the work point. It seemed apparent that perhaps the "worst case" possible (with the head of the worker still outside the casting) would be if the work point were completely contained within a relatively small internal cavity in which the only outlet faced the worker. All of the fume would then have to exit the casting straight back at the worker. In order to ascertain the

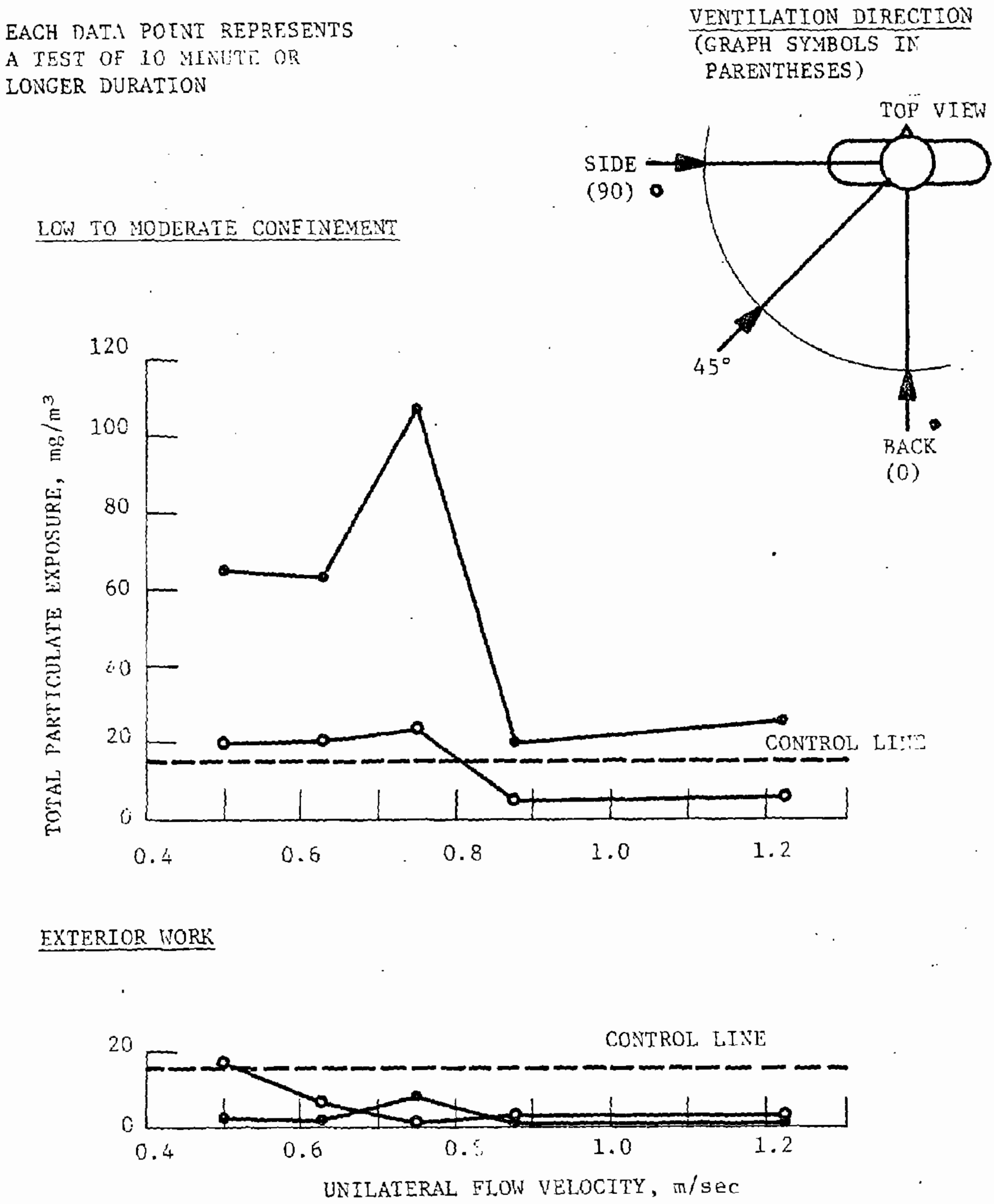


Figure 26. Results of tests during normal foundry operation: Worker exposure during high production air carbon-arc gouging in a unilateral horizontal flow booth at different ventilation directions.

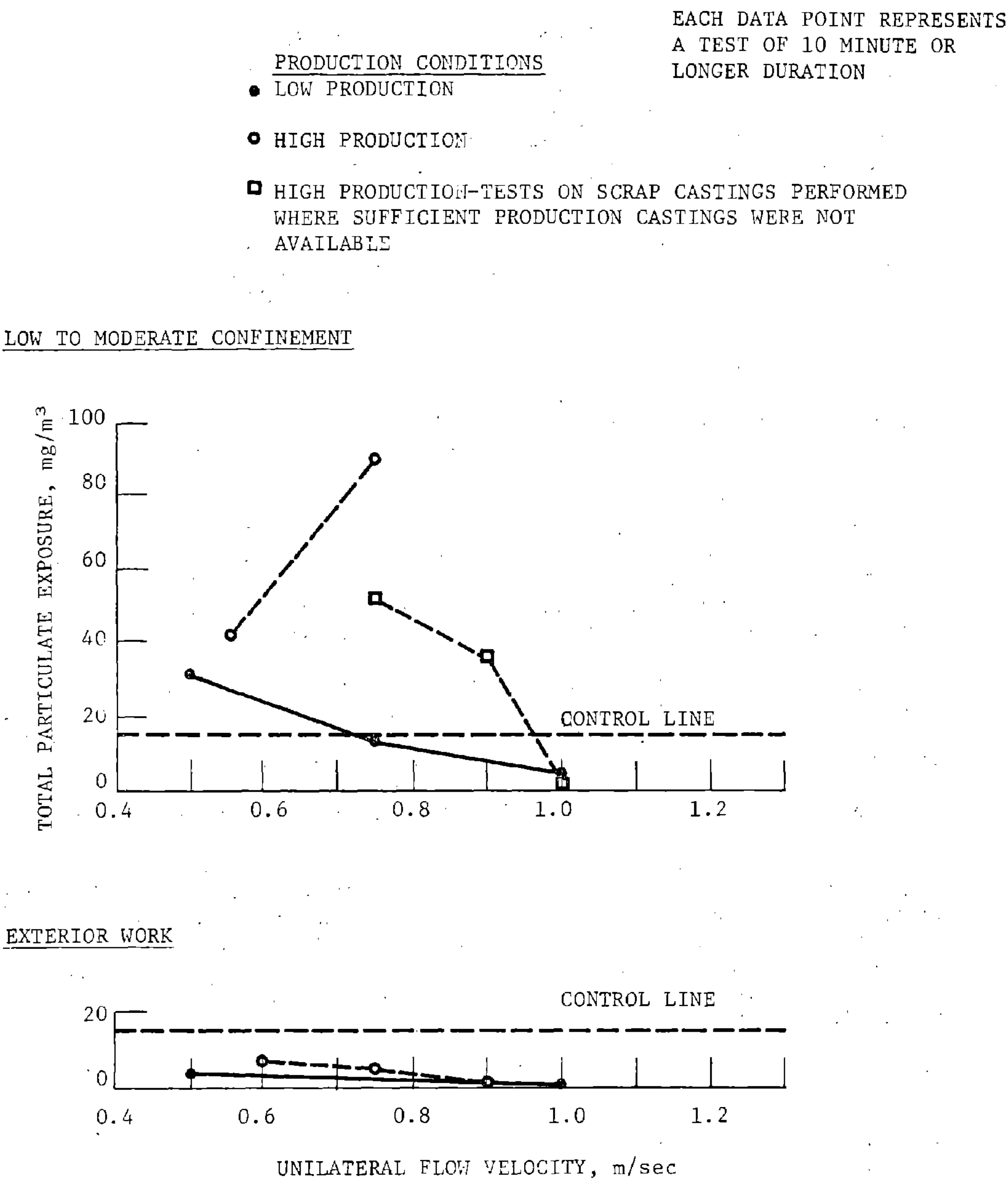


Figure 27. Results of tests during normal foundry operation: Worker exposure during air carbon-arc gouging in a unilateral flow downdraft booth at different levels of production.

effect of such a limiting condition on controllability, a cylindrical hollow scrap casting was processed with one end closed off using a plate (Figure 28). The results of these "worst case" experiments in both sidedraft and downdraft booths are presented in Figures 29-30. It can be seen that gross overexposures occurred and, although ventilation did appear to have some effect in reducing exposures, the range of velocities tested was substantially too low to achieve control. The horizontal flow tests showed again that, when the work is confined, ventilation from the back can cause a three to fivefold increase in exposure levels over ventilation from the side. In addition, reducing air flow rate through the tool by 20-30% did not substantially reduce the "splashback" under these conditions.

Torch Cutting--

Control of worker exposure during torch cutting was far less difficult than control of air carbon-arc gouging, primarily due to the nature of cutting, which is far less confining than gouging. Unlike gouging, cutting is typically done by penetrating completely through a casting to sever off a portion of it (Figure 31). The cutting swarf and the fume follow the pattern of this penetration and are projected away from the casting at the far end of the line of cutting. This mode of operation produces far less fume "splashback" than gouging, which does not often penetrate the casting, but rather removes metal swarf and fume primarily by deflection.

In the sidedraft booth, excellent control was achieved throughout the range of ventilation rates tested; in the downdraft booth a unidirectional velocity of at least 0.85 m/sec (168 ft/min) was required before worker exposures were decreased below allowable limits (Figure 32). Ventilation direction did not affect worker exposure during the sidedraft booth tests and the data presented represent averages for both ventilation conditions.

Significant "splashback" still can occur during cutting if a casting surface or workbench surface is close-by and in-line with the cut. The fume generation rate can also rise dramatically when the molten slag, as it projects away from the cut, pools against these deflecting surfaces. "Splashback" due to these causes did occur during the tests, but it was never significant.

Push-Pull Tunnel

Air Carbon-Arc Process--

Worker exposures were assessed during both exterior production work as well as during confined work on scrap at two different levels of confinement.

Unlike the unilateral flow booths, the push-pull tunnel was not fully enclosing and, therefore, fume escape into the general foundry environment was also of concern. During these tests, an area sample was gathered at a location of 1.5 m (5 ft) above the receiving exhaust hood to provide an indication of fume escape out the top of the tunnel. Since no quantitative assessment of air flow rate associated with the escaping fume was made, total emission into the workplace could not be calculated from these area samples. They were taken solely to give an indication of when escape was occurring.

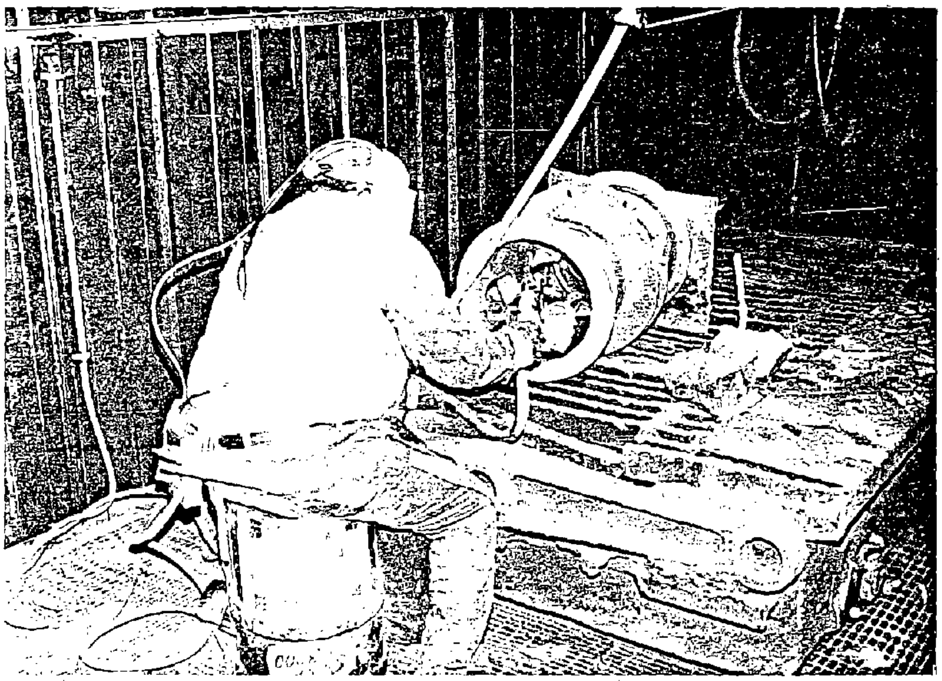


Figure 28. Type of "worst case" experiment on a scrap casting to determine the limits of controllability for the air carbon-arc gouging process. The work point is confined within a hollow, cylindrical casting with the opposite end covered with a plate.

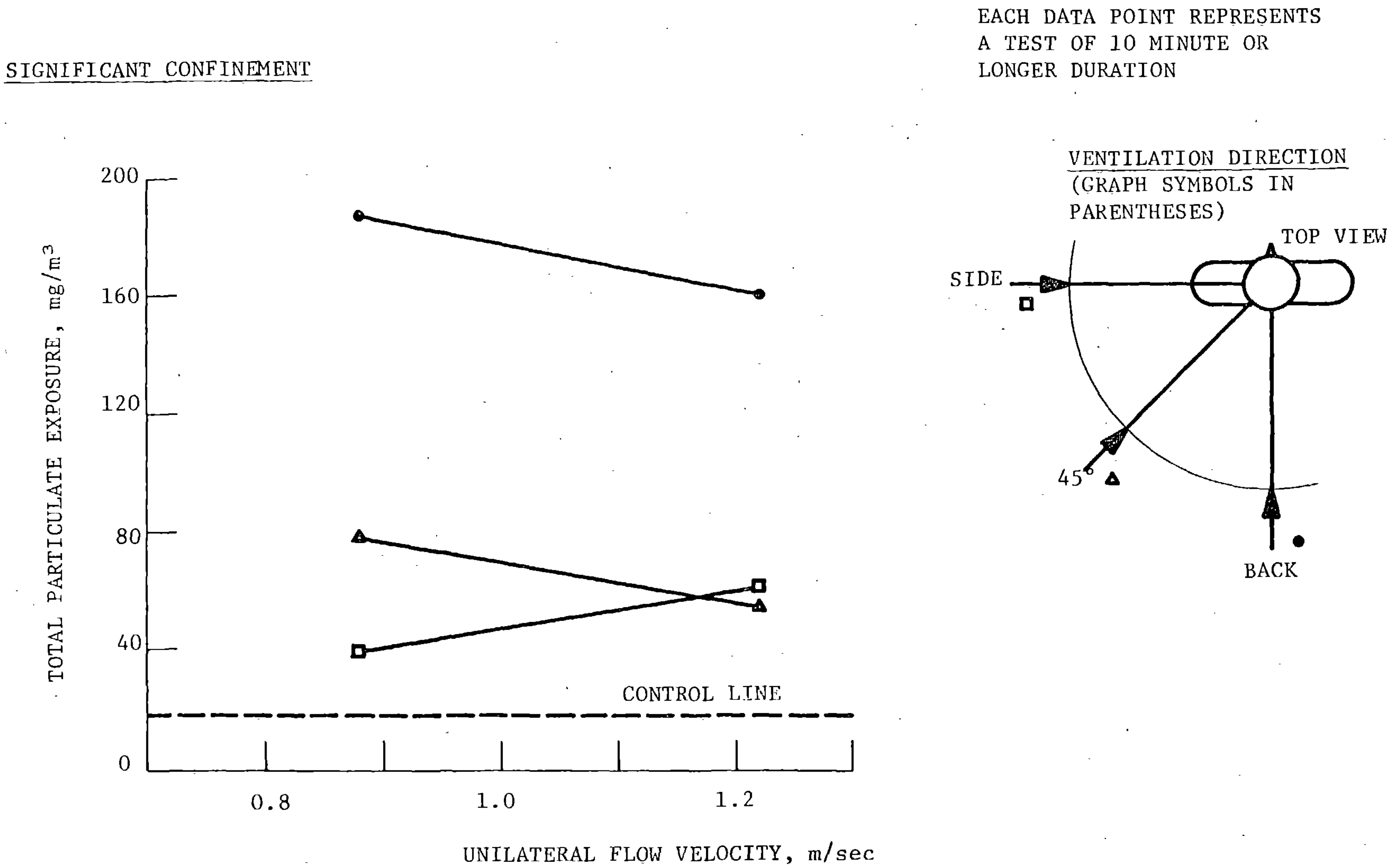


Figure 29. Results of a type of "worst case" experiment: Using "dead ended" hollow cylinder. Worker exposure during high production air carbon-arc gouging of scrap castings in a unilateral horizontal flow booth.

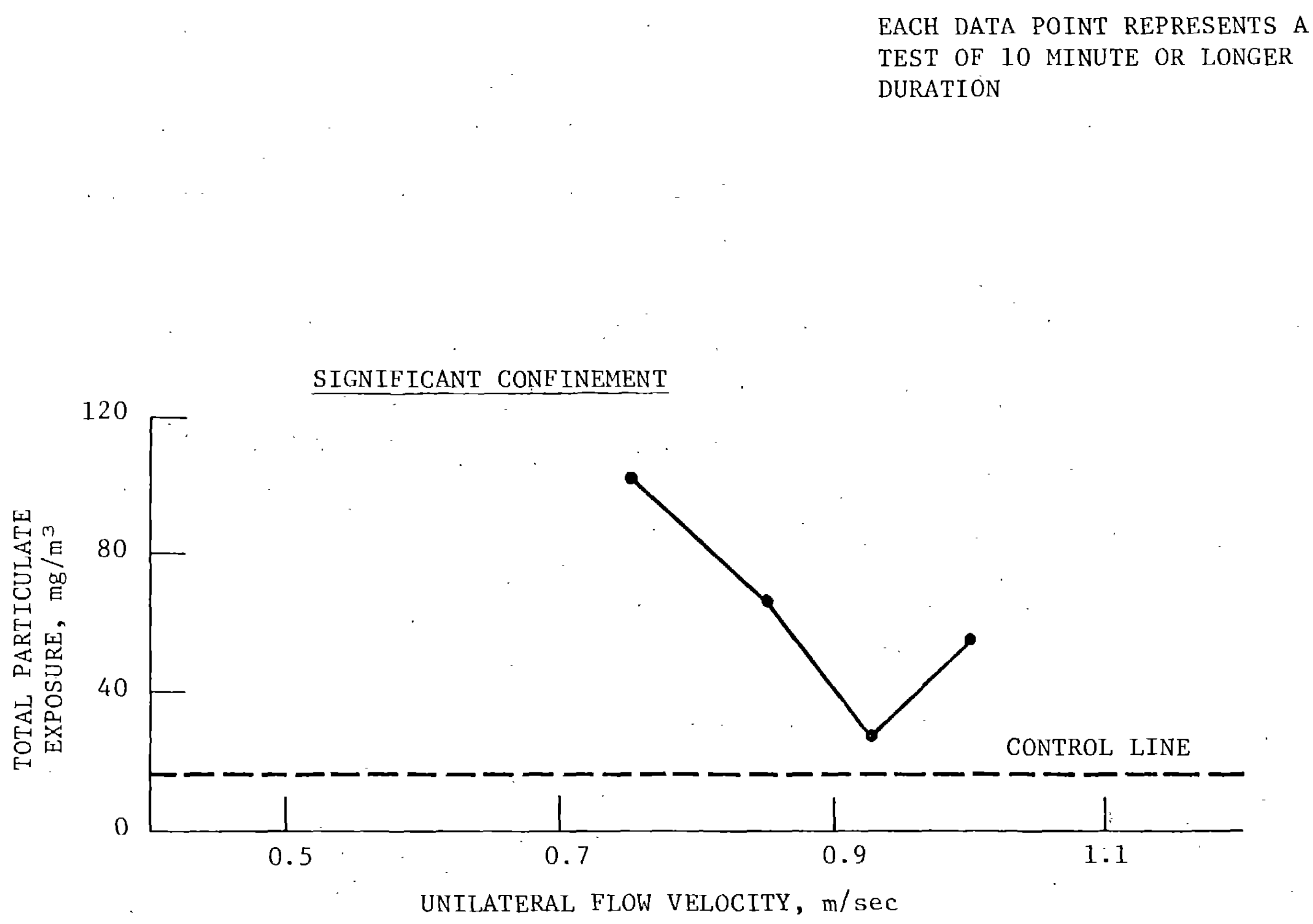


Figure 30. Results of a type of "worst case" experiment: using a "dead ended" hollow cylinder. Worker exposure during low production air carbon-arc gouging of scrap castings in a unilateral flow <u>downdraft</u> booth.

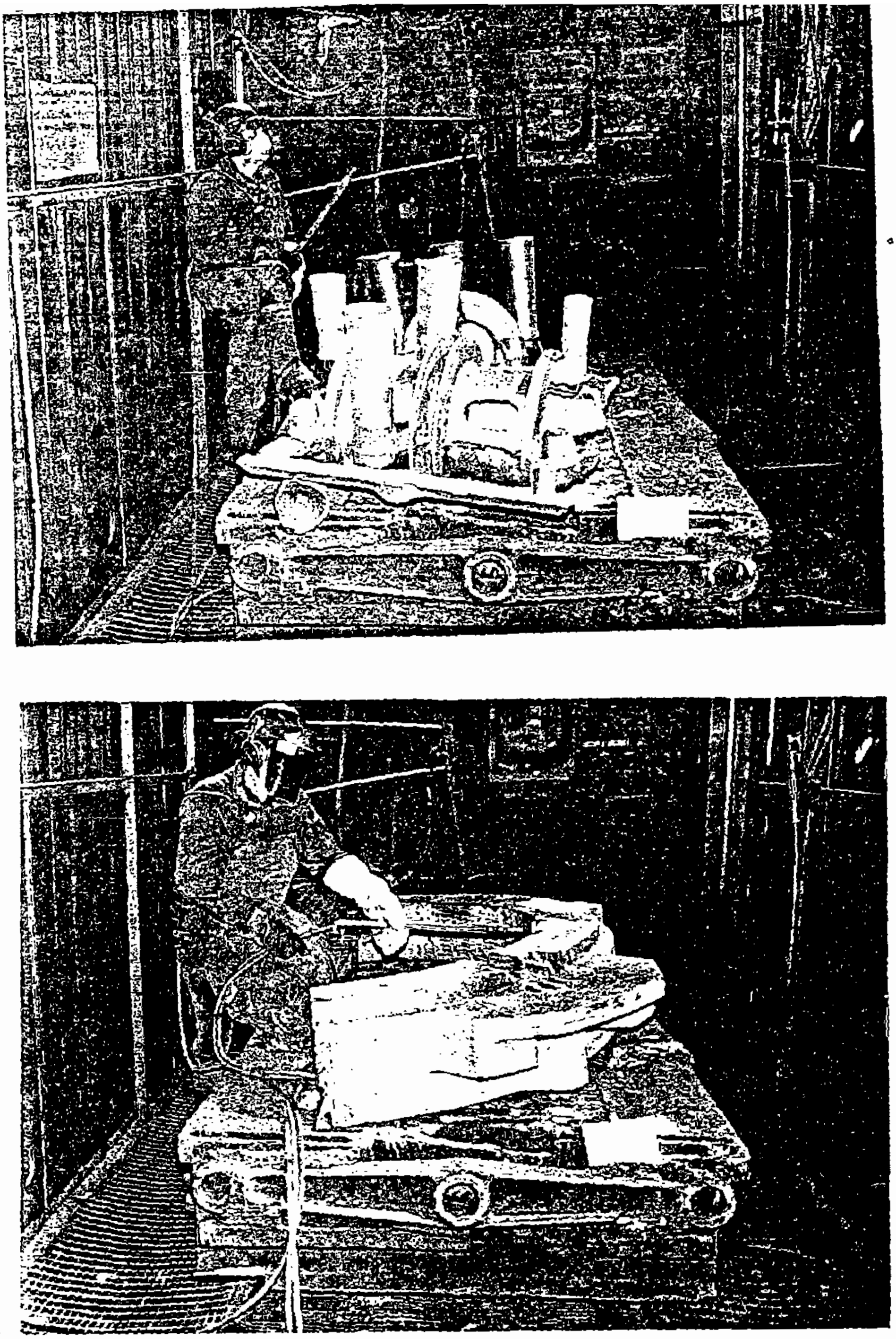


Figure 31. Typical oxy-fuel cutting operations: cutoff of casting appendages (upper photo); cutting a scrap casting in half for return to the melting furnace (lower photo).

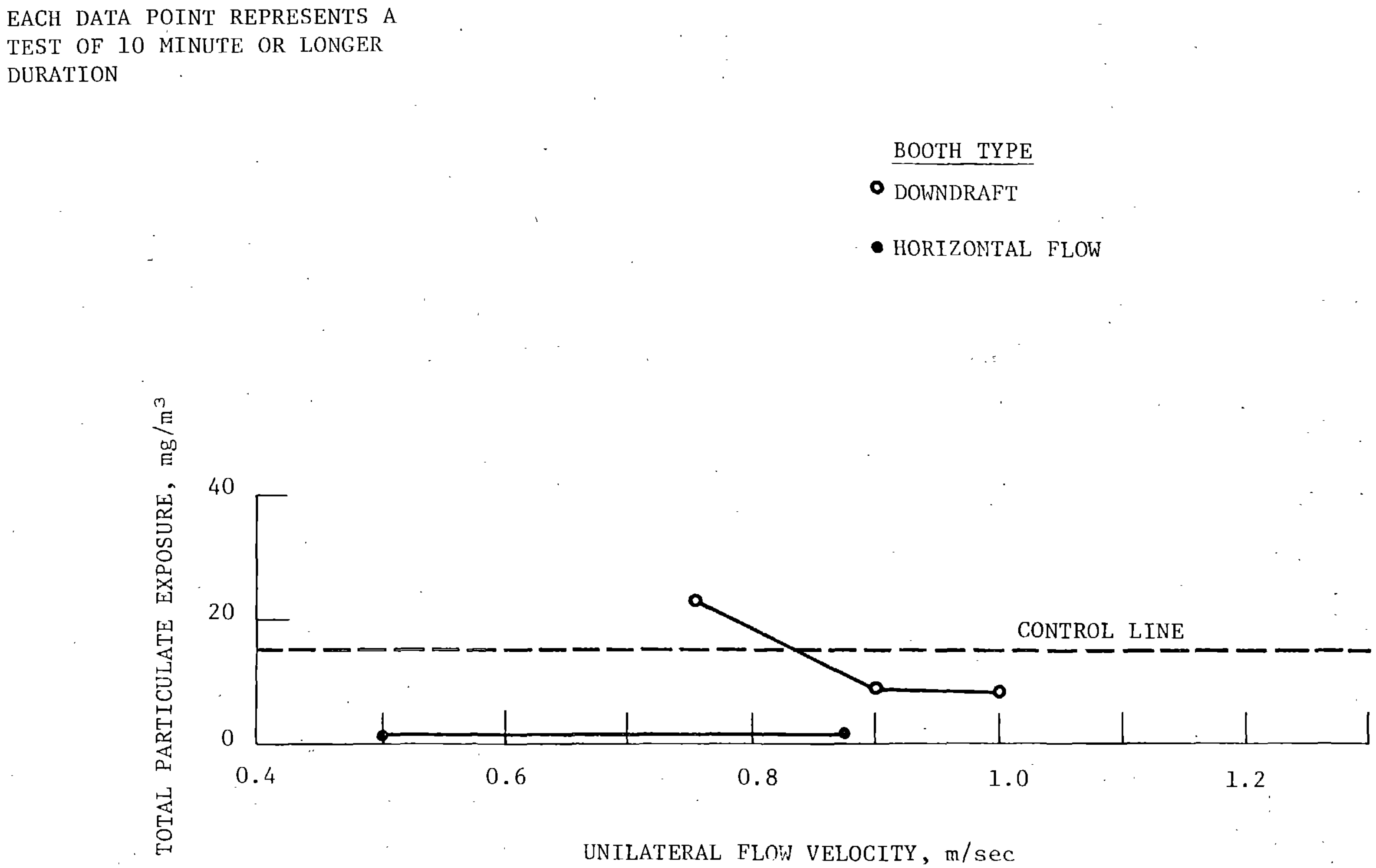


Figure 32. Results of tests during normal foundry operation: Worker exposure during oxy-fuel cutting in unilateral flow booths.

The results of these tests are shown in Table 3. As expected, exterior work was very well controlled regardless of ventilation direction. From a visual standpoint, no fume was seen to escape the tunnel under these conditions. However, the area sample showed that there was some escape and that it was slightly higher for side ventilation than for back ventilation. The probable cause for this, which was visually apparent, was from fume rebound off the sidewall.

TABLE 3. WORKER EXPOSURE DURING AIR CARBON-ARC GOUGING IN THE PUSH-PULL TUNNEL

Test	Ventilation direction	Personal sample, mg/m³	Area sample, mg/m³
Exterior (production work)	Back	B.D.L.*	2.1
Exterior (production work)	Side	0.80	4.6
Moderate confinement (experiment using large baffle)	Back	0.31	13.1
Significant confinement (type of "worst case" experiment using a "dead-ended" hollow cylinder)	Back	443	B.D.L.
	Side	113	57

*Below detectable limits.

Two sets of experiments at confined conditions were run in the push-pull tunnel. In the first, a large baffle [0.9 m wide x 1.5 m high (3 ft x 5 ft)] was placed just behind a scrap casting and the worker was instructed to cause the air jet deflecting off the casting to impact this barrier. This amount of moderate confinement had no impact on worker exposure, although some fume was seen to escape the tunnel because of the large flat barrier to air flow imposed by this baffle.

This result contrasted with the result for the unilateral horizontal flow booth, where controllability during processing under low to moderately confined conditions depended on the ventilation direction. Better control during confined work in the push-pull tunnel when ventilation was from the back probably resulted from higher air velocities in the work zone [1.5 - 2.5 m/sec (300-500 ft/min)] as opposed to 0.5 - 1.25 m/sec (100-250 ft/min) for the horizontal flow booth as well as the downward angulation of the air which tended to make the body less of a barrier to air flow in this position.

In the second experiment, the same type of "worst case" confined condition was set up as had been used in the unilateral flow booths with the same result, i.e., overexposure to fume. Fume "splashback" past the worker and against the nearby side of the booth was the reason for fume escape in the side ventilation condition.

Comparison of In-Helmet Samples with Lapel Samples

Individual filter concentrations measured during the course of the study are presented in Table 4, along with calculated ratios of lapel to in-helmet concentrations. These ratios were found to vary widely. On the average, lapel concentration exceeded in-helmet concentration for all of the control methods studied. In the case of the downdraft booth, however, in-helmet concentrations exceeded lapel samples four times out of ten. That never happened during the tests in the horizontal flow booth.

VISUAL OBSERVATIONS OF THE PROCESS

Visual observations of the operation permitted the study team to gain insights concerning fume dispersion and controllability as well as to lend credence to the real-time sampling method employed in the study.

Visual surveillance was hampered somewhat by the need to protect one's eyes from the arc flash. Two types of viewing were done:

1. Viewing of the arc point and the molten metal flow from the process using an appropriate welder's shield.

2. Completely shielding off the arc from the field of vision with an opaque shield and viewing of the visible fume in the vicinity of the breathing zone as well as throughout the booth.

The fume produced was quite visible, probably because of the high percentage of iron, and appeared white at lower concentrations but distinctly golden-brown at higher concentrations. Throughout the entire study, the real time total particulate monitor matched the pattern that was apparent from visual observation. The strip chart patterns in Figure 33 illustrate the close correlation between real-time measurements and recorded notes of the investigators.

Even the surprising variations between in-helmet and lapel filter samples were more understandable in light of the visual evidence. One could see fume rolling off of the work point as distinct puffs, some of which, depending on the particular conditions, was drawn around the sides of the helmet and breathed by the worker. Visual acuity of these puffs was clear enough, for example, to see when the fume nearly reached the sides of the helmet, but not quite, or when the puff rolled over the right shoulder and not the left. There was no question in the viewer's mind that fume concentrations surrounding the helmet were enormously variable from instant to instant, and that the helmet formed a substantial barrier to keep fume out of the helmet or retain it within.

TABLE 4. COMPARISON OF IN-HELMET VERSUS LAPEL FILTER SAMPLES

Control method	Total particulate concentration, mg/m^3, In-helmet	Lapel		Ratio of lapel sample to in-helmet sample*
Downdraft booth	8.1	13.0		1.60
	7.6	8.6		1.13
	44.6	17.5		0.39
	46.3	28.5		0.62
	62.3	60.8		0.98
	11.2	13.6		1.21
	37.3	52.3		1.40
	12.9	69.0		5.35
	19.3	109.8		5.69
	31.3	6.4		0.20
			Mean	1.86
			Range	0.20-5.69
Horizontal flow booth	17.7	23.5		1.33
	7.5	15.1		2.01
	71.7	309.6		4.32
	8.6	22.3		2.59
	15.9	36.4		2.29
	16.2	43.2		2.67
	23.1	77.4		3.35
			Mean	2.65
			Range	1.33-4.32

*These ratios should not be interpreted as constituting real protection factors because a statistical basis between in-helmet and lapel samples has yet to be established.

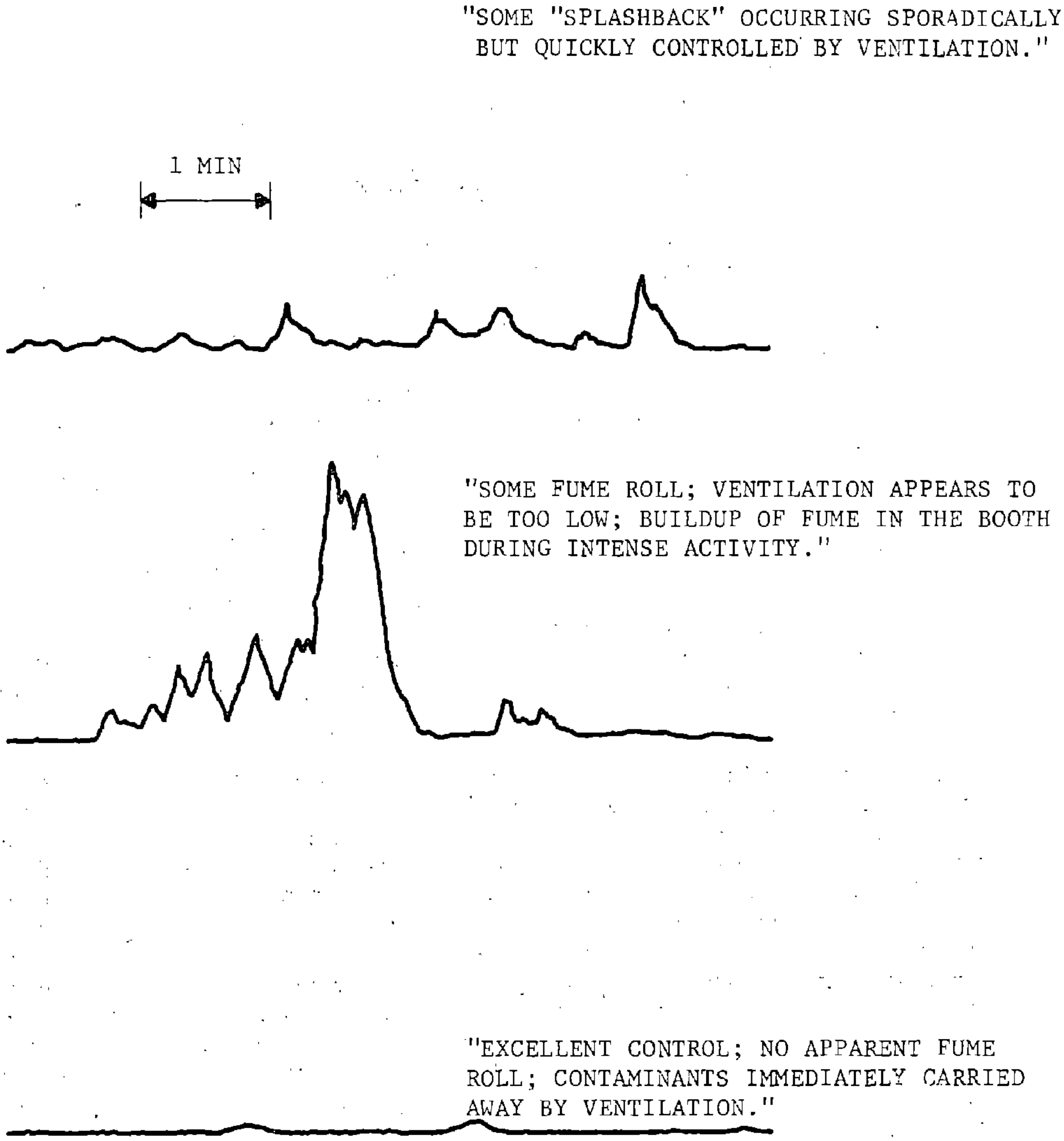


Figure 33. Typical chart recordings of real time aerosol monitor (RAM) and accompanying visual observations of the study team.

DISCUSSION

IMPLICATION OF THE TEST RESULTS FOR INDUSTRY

Control Effectiveness

The results of these tests demonstrate that enclosing, unilateral flow booths and push-pull tunnels can control worker exposure to below permissible exposure limits (PEL's) when large steel castings are processed using air carbon-arc gouging and oxy-fuel torch cutting in foundry cleaning and finishing operations. Air carbon-arc gouging is by far the more difficult of these processes to control because of the occurrence of fume "splashback" when the contact point between the electrode and the workpiece is confined. The nature of cutting as a severing operation reduces the occurrence of "splashback". As a consequence, air carbon-arc gouging generally requires a higher ventilation rate than torch cutting to protect the worker during typical production operations.

Experiments simulating higher degrees of confinement during air carbon-arc gouging than were encountered during the test program on normal foundry production show that there are limits to controllability using these ventilation methods on this particular process. As the degree of confinement of the contact point increases, both the quantity and the velocity of the "splashback" are also seen to increase, until a point is reached beyond which capture velocities are no longer capable of deflecting the fume away in the short distance between the contact point and the breathing zone. This type of "worst case" condition did not occur during the normal production runs in this test program, but it could occur in industry, even frequently, given the wide range of complex geometric forms cast in foundries. It is predictable, however, through advance knowledge of casting geometry and identification of which areas of the casting are to be processed. Air carbon-arc gouging on interior casting surfaces holds a much higher potential for "splashback" than work on exterior casting surfaces because of the confinement of the casting cavity itself. But all that is required for "splashback" is a closeby surface in line with the air jet from the tool as it deflects off the casting, therefore, exterior surfaces of castings with complex shapes also have the potential for causing substantial problems.

Besides protecting the process operator, unilateral flow booths also isolate the general work environment from a very significant air contaminant source. Push-pull tunnels, with their open tops, allow some fume escape, but it appears to be a very small percentage of the total amount generated.

Potential Range of Application

These occupational health hazard control techniques are most suitable for fixed work stations into and out of which workpieces can be transported. These methods can be scaled up in size with the only constraint being the limitation in size of castings which can be handled by available material handling systems. These methods are not easily portable which would prevent their usé during processing of very large fabricated structures, e.g., during shipbuilding. However, the push-pull tunnel does have the flexibility of being able to be temporarily erected on large production floors.

Extension to Other Processes and Materials

These control measures should also provide adequate worker protection when other forms of cutting are employed, e.g., powder burning, plasma cutting, oxygen lancing, within the constraints of controllability just discussed, but this hypothesis should be tested. The application of these booths could possibly also extend to other casting cleaning and finishing processes such as welding and chipping and grinding with portable tools.

Other workpiece materials commonly processed in industry pose equal if not greater potential hazards to the worker, especially during air carbon-arc gouging.

The majority of air carbon-arc gouging is done on regular grades of steel. Stainless steel, cast iron, copper alloys, nickel alloys and aluminum are also processed, but to a lesser extent. Control of worker exposure during processing of cast iron should produce similar results as steel. Because of the similarity of their melting and boiling points to that of iron, fume generation rates of nickel and chromium in stainless steel or nickel alloys are probably comparable to those of iron, after corrections are made because of the differing amounts of these metals in the alloy. However, the PEL's for nickel and chromium are only 10 percent of that for iron. Thus, it would take significantly less of these metals in the alloy to cause an overexposure problem than it would for iron. Processing of copper alloys poses a special problem because copper fume has a very low PEL and copper exposure from the electrode shielding alone is enough to cause a problem, let alone exposure from fume evolution from the workpiece. Further testing is necessary to establish required ventilation rates and limits of controllability for these other workpiece materials.

WORK PRACTICES

The work practice of primary importance to control of air contaminants using these ventilation methods is positioning the tool so that the air jet, as it deflects off the workpiece, moves toward the exhaust point. In a horizontal flow booth, the worker must be constantly aware of his position with respect to the ventilation direction and must reposition the workpiece as required to prevent himself from ever getting downwind of the work point.

Workers must also close the doors to the booth before beginning to work, refrain from using disruptive mancooler fans, and not set the electrode current higher than the manufacturer's recommended range.

COMPARISON OF METHODS STUDIED

Based on the test results of this demonstration study, it appears that unilateral horizontal flow booths with ventilation direction from the side of the worker are somewhat more effective than unilateral flow downdraft booths. This was particularly noticeable when "splashback" occurred during air carbon-arc gouging. Horizontal flow, encountering little obstruction, pushed the fume "splashback" to the side and away, whereas downdraft was often somewhat limited because of barriers to downward air flow caused by the work cart and/or the worker's head if he were stooped over the work. Downdraft ventilation also had to battle against the buoyancy of the hot fume. The horizontal flow booth also had less difficulty controlling fume from oxy-fuel cutting.

Although the horizontal flow booth did appear to be the more effective of the unilateral approaches tested, it constrains the operation by requiring that a turntable or other suitable workpiece repositioning method be used and that the worker operate from a relatively restricted area. The worker had no trouble with these constraints, however, and did not notice any significant difference between the two types of booths as far as performing the required processing tasks.

A significant drawback to the use of a downdraft booth is the need for a pit area which makes this method very difficult to retrofit into existing facilities. The pit area, in turn, causes a housekeeping problem because of debris and slag build up which could also foul the exhaust air distributors and restirct the ventilation of the booth.

One advantage of downdraft booths over horizontal flow booths is that the vertical height of the enclosure may be as high as desired without raising the exhaust ventilation requirement; such is not true of horizontal booths. In a horizontal flow booth, the exhaust rate is directly proportional to the height of the booth. This feature of downdraft booths may prove useful if a hoist or crane is to be installed within the booth.

During confined work, the push-pull tunnel was not as sensitive to worker position (as long as the worker was upstream or to the side of the work point) as was the horizontal flow booth, because the push-pull tunnel operated at almost twice the velocity in the work zone as the horizontal flow booth and also, perhaps, because the flow pattern in the push-pull tunnel was inclined downward, thus reducing the barrier effect to air presented by the worker's body.

Some drawbacks of the push-pull tunnel are its space requirements, the need for a second (although much smaller) fan, and the possible interference of the roof jet during loading of castings from overhead.

Incorporation into the Overall Ventilation Scheme

The problem in many foundry cleaning and finishing areas is that within one large open area a number of processes are simultaneously used which produce air contaminants, only some of which may be controlled with ventilation. These processes include those studied here, as well as other manual processes such as welding, swing grinding, and chipping and grinding using portable tools. Material handling systems, especially fork lift trucks, and housekeeping procedures, especially manual sweeping with brooms, contribute to the air contaminant problem. High background contaminant levels, to which both production and supervisory staff within the building are subjected, can result.

The ventilation technology demonstrated here, as it has been developed to date, is suitable primarily for facilities in which significant contaminant-producing processes are controlled, resulting in a background air of acceptable quality to be used as supply air for the booth. If, instead, background air quality were poor, then the allowable exposure in a ventilated booth or tunnel is effectively reduced. In particular, the allowable degree of confinement of the work point beyond which fume "splashback" causes overexposure, is reduced.

In the case of the push-pull tunnel, unless makeup air units could be placed so as to inject fresh air into the air currents induced by the air nozzles, there is no other practical alternative to drawing supply air from the general background air in the building. With the enclosed booths, however, there is the option of bringing in the supply air directly to the booths from outdoors. This air would need to be supplied through makeup air systems with the capability of tempering the incoming air, especially during cold winter months. Whether the supply air is taken from general background air or brought in directly to the booths from outdoors may not significantly effect total fuel usage for the plant, but it will have an impact on the dilution ventilation rate in the general vicinity of the booths. Recirculation of exhaust air could help reduce the energy costs associated with these ventilation methods but this approach must address two rather significant problems:

1. The need to control both gases and particulate in the return air.
2. The need to monitor to detect system failures and take action before workers are overexposed.

Recirculation of industrial exhausts is still a relatively new and untested approach in most situations.

OTHER SAFETY AND HEALTH CONCERNS

Although enclosing methods help to isolate noise, flash, and metal splatter from the rest of the facility, they do not help to protect the process operator himself, who must rely on personal protective devices.

These methods may offer little relief from the heat of the process during hot weather because the heat load is primarily direct radiation from the work point. However, if the air temperature is not so high as to cause convective heating of the worker's body, ventilation can afford some relief by enhancing sweat removal.

One area in ventilated booths which needs to be further studied is the effect of working for extended periods in a velocity field. Different sides of the worker's body can be subjected to entirely different heat fields, e.g., while the upper front of his body may be subjected to a radiation heat gain which may cause elevation in temperature and sweating of the face, chest, and front of the neck and upper arms; his upper back and the back of his head and neck may be simultaneously experiencing convection cooling from the ventilation draft.

When processes such as these are enclosed, care must be taken to assure that the worker is not so confined that he could not avoid being crushed by a shifting or toppling workpiece. In relation to the size of the workbench and casting tested during this project, the temporary test booth utilized was too narrow. As a permanent facility, a wider booth or tunnel would be necessary for this size of work.

Another safety concern is worker surveillance. In a fully enclosed booth, windows are necessary through which to monitor the worker's well-being. One foundry case history is documented in the literature where booths were constructed for processes like these to house two workers who could thus generally watch each other and also, perhaps, not feel so isolated (16). Common booths, either horizontal, vertical or push-pull tunnels are feasible, provided that proper barriers are used to prevent the molten metal from one operation to splatter on the adjacent worker.

THE WELDING HELMET AND ITS EFFECT ON EXPOSURE

It was not the purpose of this study to do a statistical analysis of in-helmet versus lapel samples. Indeed, such a study comparing the different sampling techniques inside and outside the welding helmet is long overdue.

Although no conclusions can thus be drawn from such limited data, the preliminary indication is that during torch cutting and air carbon-arc gouging, the welding helmet may offer some protection against fume exposure under certain conditions. Another study of air carbon-arc gouging and powder burning in industry in which both types of samples were gathered produced a similar finding (4). The welding helmet forms a barrier between the air contaminant source and the breathing zone as well as a trap for expired air, causing some of it to be rebreathed. Both of these effects could possibly result in lower exposures than would be experienced without this barrier.

Comparison of lapel to in-helmet samples between downdraft and horizontal flow booths also seems to indicate that ventilation direction has a significant impact on these measures.

In the helmet does indeed enhance worker protection, then this protection should be taken advantage of through controlled study of different helmet configurations, processing operations and ventilation conditions.

DESIGN GUIDELINES

INTRODUCTION

Based on the experience gained during this test program, the following procedure has been developed for the design and construction of these ventilation control methods in industry. Careful attention has been paid to limiting the specifications to only those aspects which are considered essential to proper functioning of these methods, thus allowing as much flexibility as possible to accommodate the conditions of a particular workplace. Further instruction and discussion about the guidelines is indented to differentiate it from the procedures themselves. The redundancy found in these instructions and discussion among three ventilation approaches was intentional. It permits the design procedure for any of them to stand alone.

UNILATERAL HORIZONTAL FLOW BOOTHS

A basic dimensional sketch is shown in Figure 34.

1. Select a turntable or workbench size (diameter A, height B, Figure 34) based on the sizes of workpieces to be processed. The ease of performing the work should be considered when deciding on a workbench height.

    A turntable is preferred with this method because it provides the greatest assurance that the workpiece will be repositioned as necessary to provide the proper orientation between ventilation direction, breathing zone and work point. Relying on the worker to frequently reposition the workpiece will almost certainly result in tasks being performed with improper orientation.

    It may be necessary in some cases to design around several workpieces on the workbench at any one time to reduce lost time due to material handling. A caution should be stated here that these ventilation methods are not recommended as proper choices where many small workpieces are to be lined up and processed. Reference 10 presents a design which is typical of the control methods which are far more suitable for that class of work. These methods are primarily intended for large work.

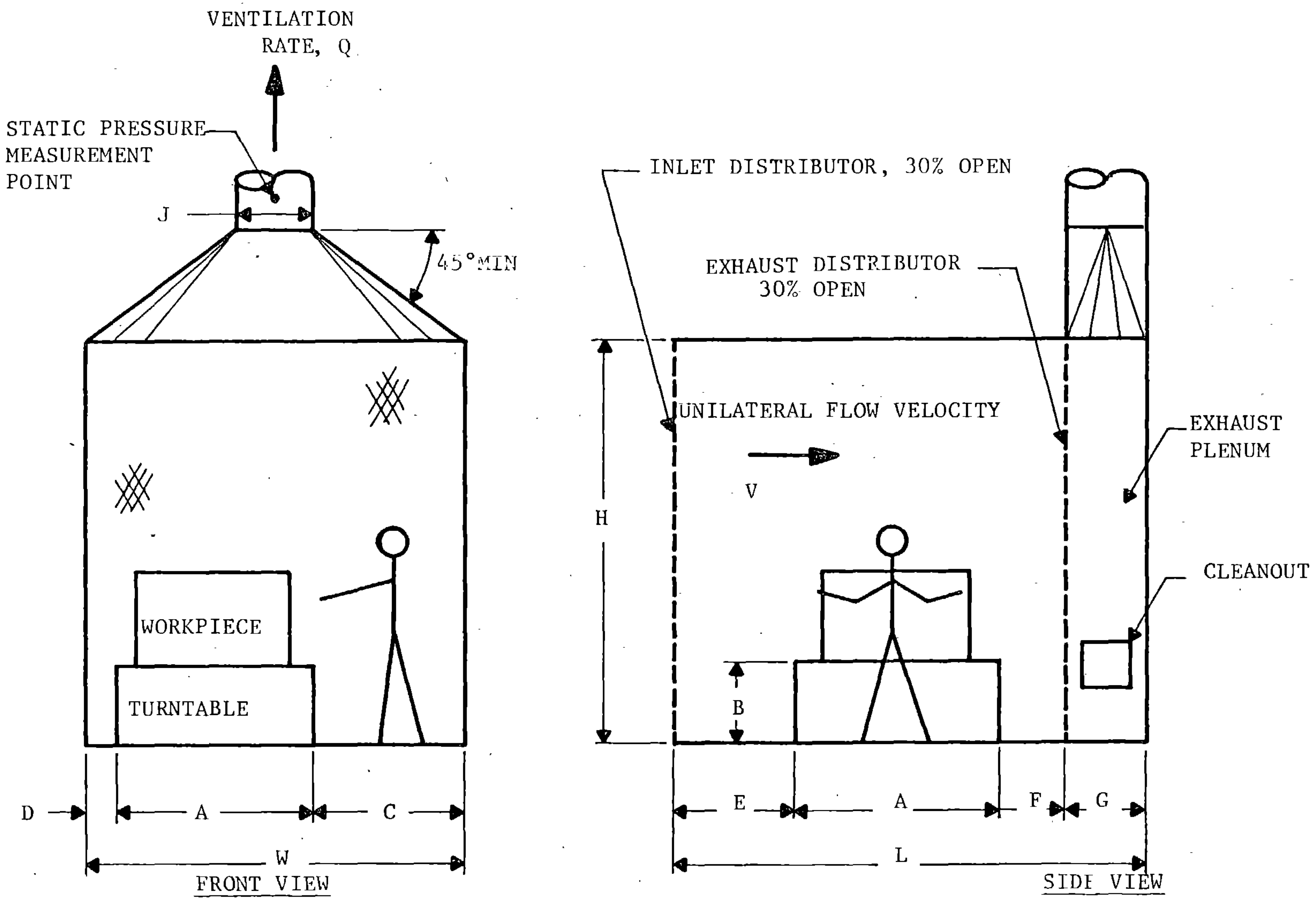


Figure 34. Dimensional sketch and other specifications for unilateral horizontal flow booth.

2. Specify a safe distance between the turntable and the booth sidewall (C, Figure 34) for the worker's station.

   Safe working implies the ability to move out of the way if a workpiece should shift or topple. It also means that the sidewall is not so close that, as the worker steps backward from the workpiece his electrode could contact the wall. Controllability was found to be better when the ventilation direction was from the side and so this should be taken advantage of in the design. It would appear that a single work station should suffice, and that stations on both sides are not required to accommodate both right and left-handed individuals. The worker's position in the booth does not have to be facing exactly sideways with the ventilation direction. The worker does have some lateral mobility to account for differences in the worker's handedness as well as differences in the complexity of workpiece geometry and the task to be performed. Providing safe worker stations on both sides may unnecessarily raise the ventilation rate, since total ventilation rate is directly proportional to booth width.

   Note that this area should be solely for the worker, not auxiliary equipment and supplies, e.g., welding machines, fuel cannisters, workbenches, boxes of electrodes, etc. The presence of these extraneous items not only represents an encumberment and a potential safety hazard, it also interferes with the uniform ventilation patterns upon which this method is based. However, although equipment itself in the booth should be minimized, electrical and gas shutoffs and other necessary controls to safely and efficiently accomplish the process should remain.

3. Specify a clearance distance (D, Figure 34) on the far side of the turntable.

   This distance must account for any overhang in the workpiece over the edge of the workbench. If the turntable is powered, it must also provide sufficient distance to prevent crushing of the worker between the workpiece and the wall if the table were accidentally rotated with the worker standing on it. Similar to dimension C, this distance should not be set arbitarily high because it directly affects total ventilation rate.

4. Specify clearance distances on the supply air and exhaust sides of the workbench (E and F, Figure 34).

   Neither of these dimensions affects total ventilation rate and, unless there is a space problem where this booth is to be installed, more clearance should be provided, perhaps 1 m (3 ft) on the upstream side (dimension E) and half this distance on the downstream side (dimension F) to produce a longer unilateral flow path, which, in turn, helps to reduce air turbulence.

5. Select a booth height (H, Figure 34).

Booth height will depend to some extent on the size range of workpieces to be processed but it should be high enough to provide proper lighting within the booth. It should under no circumstances restrict the worker from assuming any required work position. For example, if some tasks require the worker to stand on the workbench or the workpiece, the booth must be high enough to safely do this. Like booth width, booth height directly affects total ventilation rate and it should be established with that in mind.

6. Calculate total ventilation rate from the booth dimensions.

Total ventilation rate (Q, Figure 34) is calculated as follows:

$Q = AV$

Where:

Q = Total ventilation rate, m^3/sec (ft^3/min)

A = Flow cross-sectional area, m^2 (ft^2)
= WH (Figure 34)

V = Unilateral flow velocity m/sec (ft/min)
= Specific to the application*.

It should be noted that it is improper to conserve on total ventilation rate by providing flow distribution across only a portion of the cross-section of a booth. This creates undesirable turbulence and fume pockets which increase the residence time of air contaminants within the booth, resulting in higher worker exposures.

*For processing of steel workpieces using air carbon-arc gouging, a unilateral flow velocity of at least 0.8 m/sec (160 ft/min) is needed where there is low to moderate amount of confinement of the contact point of the electrode against the workpiece (see study results). During oxy-fuel torch cutting, a lower velocity may be adequate, but never lower than 0.5 m/sec (100 ft/min). Other workpiece materials and processes should be tested before finalization of a flow velocity for them.

7. Provide supply air distribution using a panel that has about 30 percent open area, with openings spaced uniformly throughout the entire cross-section.

The purposes of the supply air distributor are threefold:

a. To prevent fume escape from the booth.
b. To prevent disruption from crossdrafts.
c. To assist in uniform flow distribution.

In theory, the exhaust distribution panel is sufficient to create unidirectional flow patterns within the booth, but because the workpiece and workbench are large, the presence of the supply air distributor upstream of these flow barriers helps to provide uniform patterns throughout the work zone. Testing has shown that, even with sufficient ventilation in use, fume roll still sometimes occurs and fume can escape the booth unless higher supply air velocities are used. These inlet velocities, in turn, because they are higher than the velocities in the booth as a whole, should not be set excessively high, i.e., by restricting the open area even further, or disruptive turbulence within the booth will result. A thirty percent open supply air panel should not cause harmful turbulence if the air is well distributed.

If additional noise attenuation or protection of personnel outside the booth from welder's flash is desired, a baffled type of supply may be employed such as is suggested for the air inlet to abrasive blasting booths (18).

8. Provide exhaust air distribution over the entire cross-sectional area of the booth.

The exhaust air panel and the exhaust plenum behind it are designed as a single unit. There is much more flexibility in this design than there is in the supply air distributor because the only goal here is to distribute the air; velocities through the panel are of little consequence with the exception that excessive velocity through this panel will be wasteful of energy. An open area of thirty percent has been found effective for this purpose if:

1. The air is well distributed throughout the panel.

2. The plenum is sufficiently deep (G, Figure 34)*and a proper exhaust transition is utilized. A proper transition which can be used on the top or sides of the plenum is shown. If the exhaust transition is to be on the backwall, then multiple exhaust points should be used or, if a single exhaust point is desired, the plenum depth should be increased.

*At least as deep as the discharge duct diameter, J (see Item 9).

9. Design the ductwork system and size a blower using the Industrial Ventilation Manual (19).

Use a transport velocity of at least 15 m/sec (3000 ft/min). This translates into a duct diameter (J, Figure 34) as follows:

$$J = 30 \sqrt{Q} \text{ cm} \quad (J = 0.25 \sqrt{Q} \text{ inches})$$

Blower static pressure will depend on the configuration of the ductwork system and whether or not an air cleaner is used. Hood entry loss of at least 2.5 cm (1 in.) should be allowed for. It is recommended that sufficient safety factor be used in the blower sizing to permit optimization of a unilateral flow velocity, V, for the booth. Belt driven fans are recommended to provide flexibility for flow changes.

10. Other design considerations.

Doors can be placed into either of the two sidewalls, the roof, or the supply air distributor to transport the workpiece into and out of the booth. If a separate pedestrian door is used, it should be placed as far upstream as possible, i.e., at the supply air side. The pedestrian door should be self closing.

An access door should be placed in the exhaust plenum at the back of the booth to clean out settled particulate and slag.

The structure of the booth should be on the outside and the inside surfaces of the booth should consist of smooth walls to minimize air turbulence.

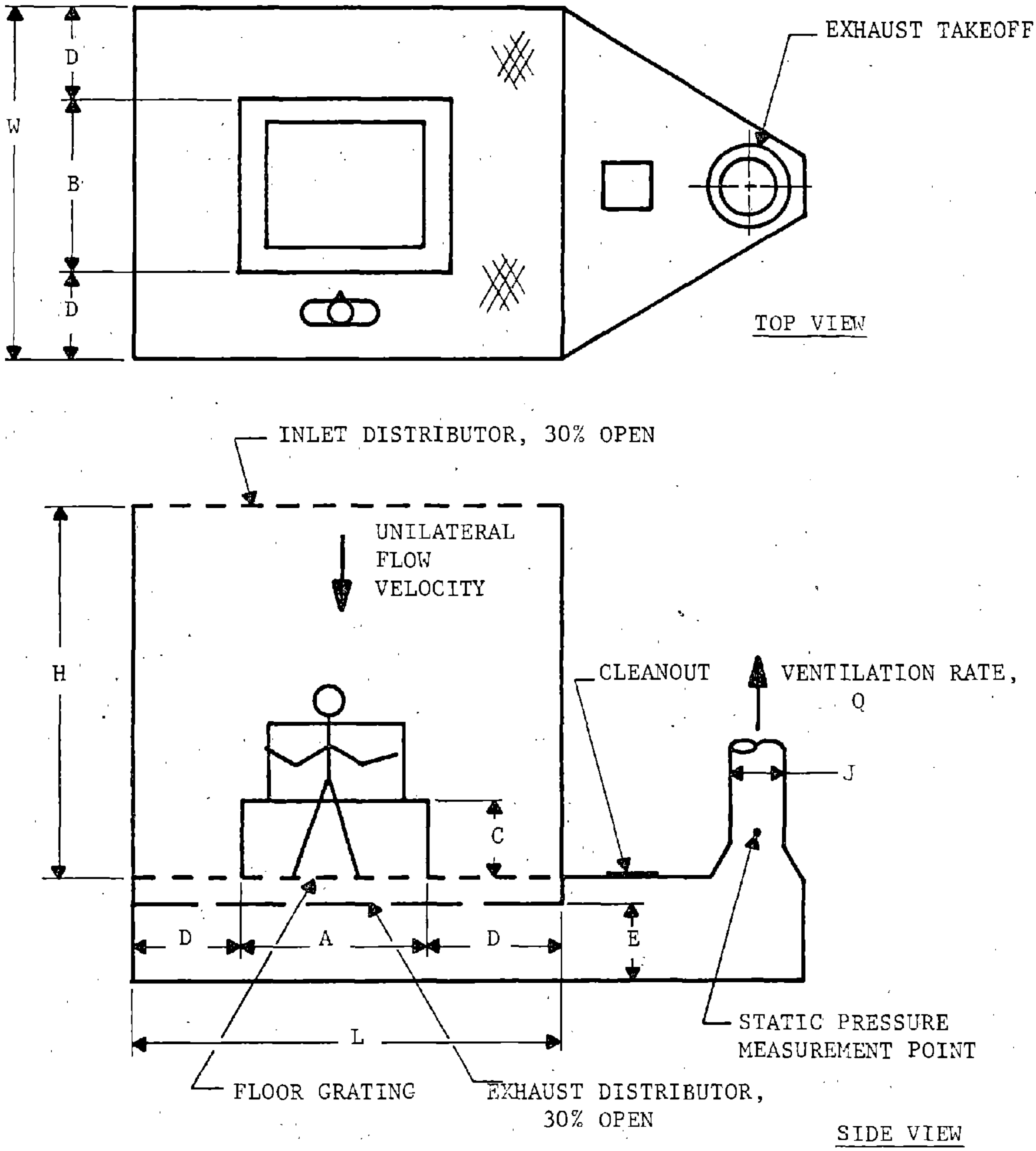
Mancooler fans should not be used inside the booth because they create disruptive amounts of air turbulence.

A static pressure gauge should be installed in the ductwork just downstream of the hood transition to monitor booth flow conditions.

UNILATERAL FLOW DOWNDRAFT BOOTHS

A basic dimensional sketch is shown in Figure 35.

1. Select a workbench size (length A, width B, height C, Figure 35) based on the sizes of workpieces to be processed. The ease of performing the work should be considered when deciding on a workbench height.



NOTE: STRUCTURAL SUPPORTS NOT SHOWN.

Figure 35. Dimensional sketch and other specifications for unilateral flow downdraft booth.

It may be necessary in some cases to design around several workpieces on the workbench at any one time to reduce lost time due to material handling. A caution should be stated here that these ventilation methods are not recommended as proper choices where many small workpieces are to be lined up and processed. Reference 10 presents a design which is typical of the control methods which are far more suitable for that class of work. These methods are primarily intended for large work.

2. Specify a safe distance between the workbench and the booth walls (D, Figure 35) for the worker's station.

   Safe working implies the ability to move out of the way if a workpiece should shift or topple. It also means that the sidewall is not so close that, as the worker steps backward from the workpiece his electrode could contact the wall.

   Controllability in the downdraft booth is independent of worker position around the workbench, therefore, safe access needs to be provided on all sides.

   Note that this area should be solely for the worker, not auxiliary equipment and supplies, e. g., welding machines, fuel cannisters, workbenches, boxes of electrodes, etc. The presence of these extraneous items not only represents an encumberment and a potential safety hazard, it also interferes with the uniform ventilation patterns upon which this method is based. However, although equipment itself in the booth should be minimized, electrical and gas shutoffs and other necessary controls to safely and efficiently accomplish the process should remain.

3. Select a booth height (H, Figure 35).

   Booth height will depend to some extent on the size range of workpieces to be processed but it should be high enough to provide proper lighting within the booth. It should under no circumstances restrict the worker from assuming any required work position. For example, if some tasks require the worker to stand on the workbench or the workpiece, the booth must be high enough to safely do this.

4. Calculate total ventilation rate from the booth dimensions.

   Total ventilation rate (Q, Figure 35) is calculated as follows:

   $Q = AV$

   where

   Q = Total ventilation rate, m^3/sec (ft^3/min)

   A = Flow cross-sectional area, $m^2/(ft^2)$

= WL (Figure 35)
V = Unilateral flow velocity m/sec (ft/min)
= Specific to the application*

It should be noted that it is improper to conserve on total ventilation rate by providing flow distribution across only a portion of the cross-section of a booth. This creates undesirable turbulence and fume pockets which increase the residence time of air contaminants within the booth, resulting in higher worker exposures.

5. Provide supply air distribution using a panel that has about 30 percent open area, with openings spaced uniformly throughout the entire cross-section.

The purposes of the supply air distributor are threefold:

a. To prevent fume escape from the booth.
b. To prevent disruption from crossdrafts.
c. To assist in uniform flow distribution.

In theory, the exhaust distribution panel is sufficient to create unidirectional flow patterns within the booth, but because the workpiece and workbench are large, the presence of the supply air distributor upstream of these flow barriers helps to provide uniform patterns throughout the work zone.

Testing has shown that, even with sufficient ventilation in use, fume roll still sometimes occurs and fume can escape the booth unless higher supply air velocities are used. These inlet velocities, in turn, because they are higher than the velocities in the booth as a whole should not be set excessively high i.e., by restricting the open area even further, or disruptive turbulence within the booth will result. A thirty percent open supply air panel should not cause harmful turbulence if the air is well distributed.

If additional noise attenuation or protection of personnel outside the booth from welder's flash is desired, a baffled type of supply may be employed such as is suggested for the air inlet to abrasive blasting booths (18).

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*For processing of steel workpieces using air carbon-arc gouging, a unilateral flow velocity of at least 1.0 m/sec (200 ft/min) is needed where there is low to moderate amount of confinement of the contact point of the electrode against the workpiece (see study results). During oxy-fuel torch cutting, a lower velocity may be adequate, but never lower than 0.5 m/sec (100 ft/min). Other workpiece materials and processes should be tested before finalization of a flow velocity for them.

6. Provide exhaust air distribution over the entir floor area of the booth

To prevent fouling with slag, pieces of removable, open grating should be placed over the entire floor. The percent of open area in this grating is not of concern for ventilation purposes; the only concerns are providing a safe work surface that will not clog easily with debris.

If the exhaust takeoff is from one end of the pit only, then removable metal baffles can be used below the floor grating for flow balancing. Slot width can be adjusted as necessary to achieve good flow balance and then stops can be welded onto beams upon which these baffles rest so that the baffles can subsequently be removed for cleanout of the pit and then returned to the proper locations. An open area in the baffle partitions of thirty percent should be effective for this purpose if:

1. The slots between baffles are distributed throughout the floor.

2. The pit is sufficiently deep (E, Figure 35)* and a proper exhaust transition is utilized. A proper transition which can be used when the exhaust comes off one side of the pit is shown.

7. Design the ductwork system and size a blower using the Industrial Ventilation Manual (19).

Use a transport velocity of at least 15 m/sec (3000 ft/min). This translates into a duct diameter (J, Figure 35) as follows:

$$J = 30\sqrt{Q} \text{ cm } (J = 0.25\sqrt{Q} \text{ inches})$$

Blower static pressure will depend on the configuration of the ductwork system and whether or not an air cleaner is used. Hood entry loss of at least 2.5 cm (1 in.) should be allowed for. It is recommended that sufficient safety factor be used in the blower sizing to permit optimization of unilateral flow velocity, V, for the booth. Belt driven fans are recommended to provide flexibility for flow changes.

*At least as deep as the discharge duct diameter, J (see Item 7).

8. Other design considerations.

Doors can be placed into any of the sidewalls or the roof to transport the workpiece into and out of the booth. If separate pedestrian door is used, it should be self-closing.

An access door should be installed in the exhaust plenum just before the transition to vertical ducting to clean out settled particulate in this zone.

The structure of the booth should be on the outside and the inside surfaces of the booth should consist of smooth walls to minimize air turbulence.

Mancooler fans should not be used inside the booth because they create disruptive amounts of air turbulence.

A static pressure gauge should be installed in the ductwork just downstream of the transition to vertical ducting to monitor booth flow conditions.

PUSH-PULL TUNNEL

The construction details provided here are essentially those tested during the demonstration study, with latitude provided for varying the width of the tunnel. The positions of the slit nozzles and the ratio of nozzle flows to total ventilation rate are fixed. The use of this method does not necessarily require that these parameters be fixed, however, testing would be required to assure proper performance using other arrangements.

A basic dimensional sketch is shown in Figure 36.

1. Select a turntable or workbench size (diameter A, height B, Figure 36) based on the sizes of workpieces to be processed. The ease of performing the work should be considered when deciding on a workbench height.

   A turntable is preferred with this method because it provides the greatest assurance that the workpiece will be repositioned as necessary to provide the proper orientation between ventilation direction, breathing zone and work point. Relying on the worker to frequently reposition the workpiece will almost certainly result in tasks being performed with improper orientation.

   It may be necessary in some cases to design around several workpieces on the workbench at any one time to reduce lost time due to material handling. A caution should be stated here that these ventilation methods are not recommended as proper choices where many small workpieces are to be lined up and processed. Reference 10 presents a design which is typical of the control methods which are far more suitable for that class of work. These methods are primarily intended for large work.

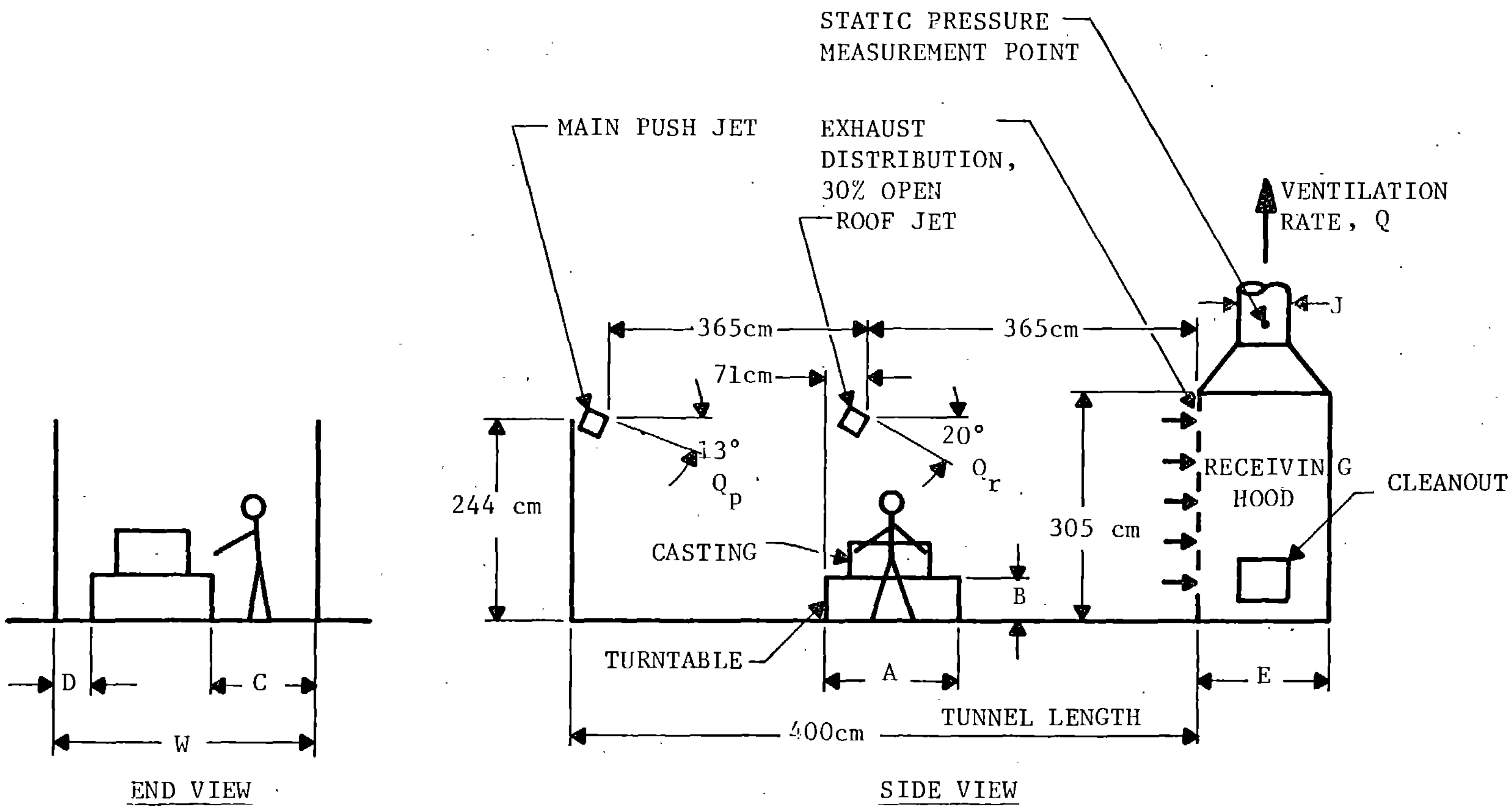

Figure 36. Dimensional sketch and other specifications for push-pull tunnel.

2. Specify a safe distance between the turntable and the booth sidewall (C, Figure 36) for the worker's station.

Safe working implies the ability to move out of the way if a workpiece should shift or topple. It also means that the sidewall is not so close that, as the worker steps backward from the workpiece his electrode could contact the wall. Controllability was found to be better when the ventilation direction was from the side and so this should be taken advantage of in the design. It would appear that a single work station should suffice, and that stations on both sides are not required to accommodate both right and left-handed individuals. The worker's position in the booth does not have to be facing exactly sideways with the ventilation direction. The worker does have some lateral mobility to account for differences in the worker's handedness as well as differences in the complexity of workpiece geometry and the task to be performed. Providing safe worker stations on both sides may unnecessarily raise the ventilation rate, since total ventilation rate is directly proportional to booth width.

Note that this area should be solely for the worker, not auxiliary equipment and supplies, e.g., welding machines, fuel cannisters, workbenches, boxes of electrodes, etc. The presence of these extraneous items not only represents an encumberment and a potential safety hazard, it also interferes with the uniform ventilation patterns upon which this method is based. However, although equipment itself in the booth should be minimized, electrical and gas shutoffs and other necessary controls to safely and efficiently accomplish the process should remain.

3. Specify a clearance distance (D, Figure 36) on the far side of the turntable.

This distance must account for any overhang in the workpiece over the edge of the workbench. If the turntable is powered, it must also provide sufficient distance to prevent crushing of the worker between the workpiece and the wall if the table were accidentally rotated with the worker standing on it. Similar to dimension C, this distance should not be set arbitrarily high because it directly affects total ventilation rate.

4. Calculate total ventilation rate from the booth dimensions.

Total ventilation rate (Q, Figure 36) is calculated as follows:

$Q = 0.033\ W$ $\quad (Q = 180\ W)$

<u>Where</u>:
Q = Total ventilation rate, m^3/sec (ft^3/min)
W = Tunnel width, cm (in.)

5. Calculate nozzle flow rates from the booth dimensions.

Main pushjet supply air rate (Q_p, Figure 36) is calculated as follows:

$Q_p = 0.002W$ $\qquad$ ($Q_p = 10.7W$)

Where:

Q_p = Main pushjet flow rate, m^3/sec (ft^3/min)

W = Tunnel width, cm (in.)

Roof jet supply air rate (Q_r, Figure 36) is calculated as follows:

Roof jet supply air rate (Q_r, Figure 36) is calculated as follows:

$Q_r = 0.0009W$ $\qquad$ ($Q_r = 4.6W$)

Where:

Q_r = Roof jet flow rate, m^3/sec (ft^3/min)

W = Tunnel width, cm (in.)

6. Construct nozzles to provide uniform push velocities across the width of the booth.

A typical nozzle design is shown in Figure 37. Some specifications to note are:

1. The slit should be elongated (10 cm long, Figure 37) and not just constructed as an orifice slit.

2. Braces should be used to control slit width along the entire length of the slit (slit adjusters, Figure 37). Threaded rod was used in the test tunnel.

3. The slit should not be relied on to distribute the air. A backup distributor (Figure 37) is needed to assure equal distribution. Pegboard was used in the test tunnel.

4. The plenum size should be based on the booth width, W. For booth widths of 300 cm or less the 30 cm x 30 cm size should be sufficient, provided at least two duct entries are used.

5. Design the exhaust ductwork system and size a blower using the Industrial Ventilation Manual (19).

7. Provide exhaust air distribution over the entire cross-sectional area of the receiving hood.

The exhaust air panel and the exhaust plenum behind it are designed as a single unit. There is much more flexibility in this design than there is in the supply air distributor because the only goal here is to distribute the air; velocities through the panel are of little consequence with the exception that excessive velocity through this panel will be wasteful of energy. An open area of thirty percent has been found effective for this purpose if:

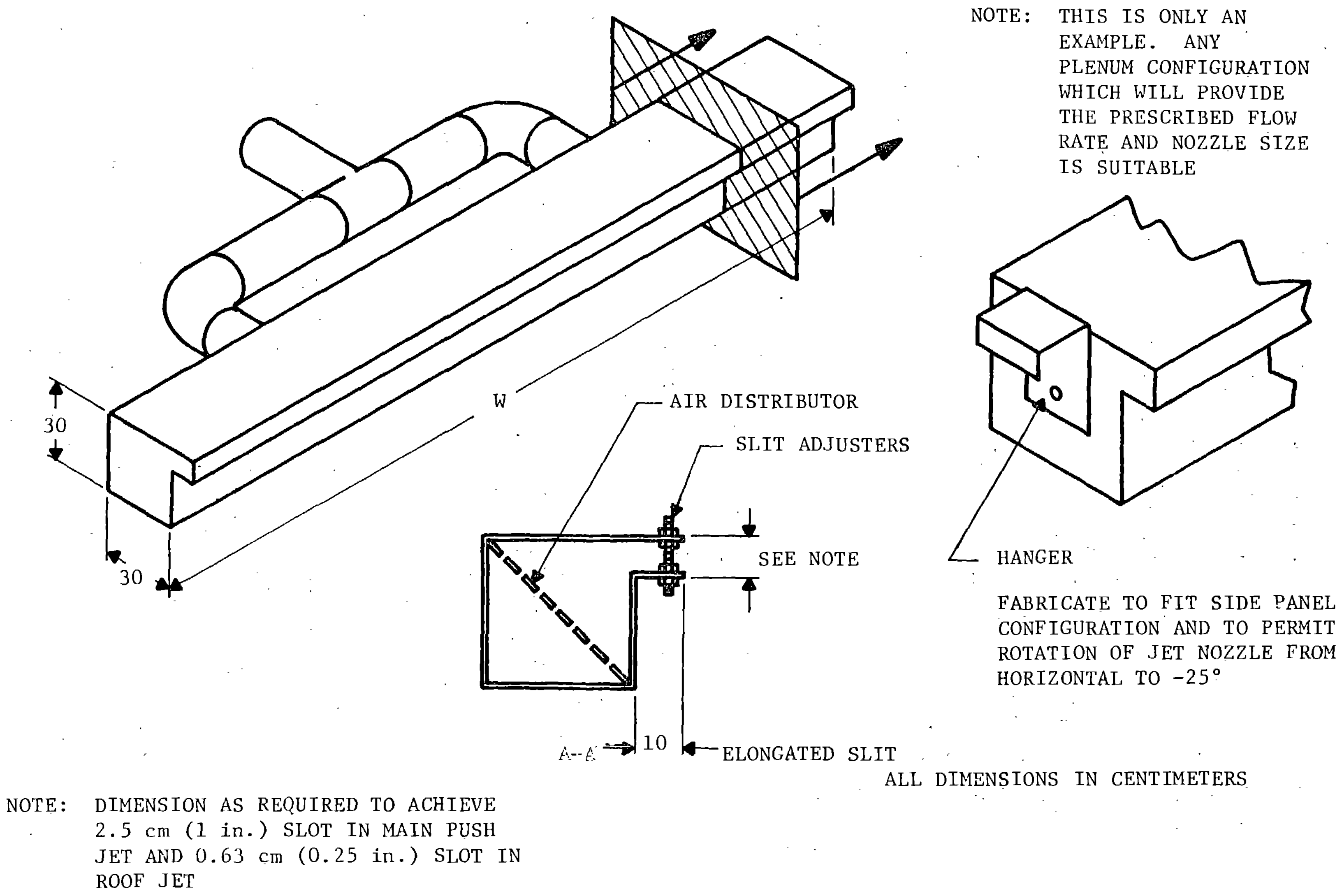

Figure 37. Example of nozzle design: Push-pull tunnel.

1. The air is well distributed throughout the panel.

2. The plenum is sufficiently deep (E, Figure 36)* and a proper exhaust transition is utilized. A proper transition which can be used on the top or sides of the plenum is shown. If the exhaust transition is to be on the backwall, then multiple exhaust points should be used or, if a single exhaust point is desired, the plenum depth should be increased.

8. Design the exhaust ductwork system and size a blower using the Industrial Ventilation Manual (19).

Use a transport velocity of at least 15 m/sec (3000 ft/min). This translates into a duct diameter (J, Figure 34) as follows:

$J = 30\sqrt{Q}$ cm ($J = 0.25\sqrt{Q}$ inches)

Blower static pressure will depend on the configuration of the ductwork system and whether or not an air cleaner is used. Hood entry loss of at least 2.5 cm (1 in.) should be allowed for. It is recommended that sufficient safety factor be used in the blower sizing to permit optimization of the system. Belt driven fans are recommended to provide flexibility for flow changes.

9. Other design considerations.

The roof jet could be made movable for unencumbered overhead access for loading of the workbench by crane.

An access door should be placed in the exhaust plenum to clean out settled particulate and slag.

The support structure of the tunnel should be on the outside. The inside surfaces should consist of smooth walls to minimize air turbulence.

Mancooler fans should not be used inside the tunnel because they create disruptive amounts of air turbulence.

A static pressure gauge should be installed in the ductwork just downstream of the hood transition to monitor booth flow conditions. Gauges should also be used upstream of the main pushjet and roof jet.

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*At least as deep as the discharge duct diameter, J (see Item 8).

CONCLUSIONS

1. Unilateral flow booths and "push-pull" tunnels can control worker exposure to air contaminants when large steel workpieces are processed using air carbon-arc gouging and oxy-fuel torch cutting.

2. There are limits to controllability, however, when using these ventilation methods for air carbon-arc gouging. As the contact point between the electrode and the workpiece becomes more and more confined, fume "splashback" at the worker eventually overpowers these ventilation methods. For any given process operation, the potential for significant "splashback" is predictable.

3. Besides protecting the process operator, these ventilation methods isolate a very significant source of air contaminants from the general building environment.

4. Other forms of cutting besides oxy-fuel should be controllable with these methods, e. g., powder burning, plasma cutting, and oxygen lancing. This control technology could also possibly extend to welding and grinding with portable tools.

5. Although the supply air for these ventilation methods could be brought in directly from outdoors, the ventilation technology demonstrated here is suitable primarily for facilities in which significant air contaminant-producing processes are controlled, resulting in a background air of acceptable quality to be used as supply air for the booth.

6. These ventilation approaches do not isolate the process operator from noise, metal splatter and flash. Suitable protective clothing, hearing protection and tinted viewing shields are required.

7. The added concern for the worker's safety in the isolated booth environment necessitates the use of additional surveillance procedures.

8. Preliminary indication is that under certain conditions the welding helmet offers some protection against exposure to air contaminants produced by these processes.

RECOMMENDATIONS

1. Unilateral flow booths and "push-pull" tunnels should be considered as viable approaches for controlling exposure to air contaminants during air carbon-arc gouging and oxy-fuel torch cutting of large steel workpieces. Prior to using these methods for air carbon-arc gouging, the extent of work in which the contact point between the electrode and workpiece would be confined should be determined. These ventilation approaches do not offer sufficient protection when the process is significantly confined to prevent overexposure and additional respiratory protection is required in such cases.

2. To assure that these ventilation methods are properly applied, the design and construction guidelines presented in this report should be followed. The worker should also wear personal protective devices for noise, metal splatter and flash and be frequently monitored for safety in the isolated booths.

3. Further testing should be done to establish ventilation rates and limits of controllability for other common workpiece materials such as stainless steel, other high alloy steels, and nickel and copper alloys.

4. A study should be undertaken to develop a statistical basis for comparing air sampling results both inside and outside the welding helmet. With this relationship known, the effect of the welding helmet in protecting the worker from exposure to air contaminants should be assessed and possible improvements to enhance this protection should be explored.

REFERENCES

1. Stott, M. D., and Swinburn, D. G. 1979. The assessment of dust and fume in steelfoundry fettling shops. J. of Res., Steel Castings Research and Trade Assn. (SCRATA) Great Britain, pp. 22-28.

2. Scholz, R. C., and Holcomb, M. L. 1980. Feasibility study for reduction of worker exposures to nickel and chromium in alloy foundries. Foundry Nickel Committee, William R. Dybvad, Vice-Chairman, (Duriron Co., Inc., P.O. 1145, Dayton, OH 45401).

3. Sanderson, J. T. 1968. Hazards of the arc-air gouging process. Ann. Occup. Hyg. Vol. 11, pp. 123-133.

4. Sentz, F. C., and Rakow, A. B. 1969. Exposure to iron oxide fume at arcair and powder burning operations. Am. Indus. Hyg. Assn. J., March-April, pp. 143-146.

5. Envirex, Inc. 1978. An evaluation of occupational health hazard control technology of the foundry industry. Report of the National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 79-114, Case histories 5 and 6, pp. 189-214.

6. NIOSH criteria for a recommended standard, Occupational exposure to inorganic nickel. May, 1977. DHEW Publication no. 77-164.

7. Stott, M. D. A review of successful arc air extraction systems encountered on the environmental survey programme. Steel Castings Research and Trade Association. 5 East Bank Road, Sheffield S2 3PT England.

8. Oliver, T. P., and Sanderson, J. T. 1973. Arc air gouging: the hazards and their control, J. Soc. Occup., Med., 23:114-119.

9. Hibbs, J. B. 1974. Some aspects of dust and fume control in steel foundries, Pollution Monitor, Aug-Sept., pp. 34-39.

10. Stott, M. D., et al. 1981. The SCRATA "Arcstract" System, SCRATA Research J. No. 53, June, pp. 28-33.

11. Industrial ventilation - a manual of recommended practice, 16th edition, ACGIH Committee on Industrial Ventilation, P.O. Box 16153, Lansing , MI 48901. Plate No. VS-916, Torch Cutting Ventilation.

12. Foundry environmental control, Volume 1, American Foundrymen's Society, Golf and Wolf Roads, Des Plaines, IL 60016, Chapter 8, Cleaning Room, p. 8-2.

13. Fumes and gases in the welding environment. 1979. American Welding Society, 2501 NW 7th Street, Miami, FL 33125, pp. 30-34.

14. Heriot, N. R., and Wilkinson, J. 1979. Laminar flow booths for the control of dust, Filtration and Separation Mag., Mar-Apr., pp. 159-164.

15. Holcomb, M. L., and Scholz, R. C. 1981. Evaluation of air cleaning and monitoring equipment used in recirculation systems, Report on a study for the National Institute for Occupational Safety and Health, DHEW Contract No. 210-78-0011, DHEW (NIOSH) Publication no. 81-113.

16. Scheid, J. 1981. Pelton Casteel's new cleaning room. In Proceedings of the Symposium on Occupational Health Hazard Control Technology in the Foundry and Secondary Non-Ferrous Smelting Industries. NIOSH Publication No. 81-114., pp. 64-71.

17. Beaulieu, H. J., et. al. October 1980. A comparison of aerosol sampling techniques: "open" versus "closed-face" filter cassettes. Am. Ind. Hy. Assoc. J. (41) p. 758-765.

18. Industrial ventilation - a manual of recommended practice, ACGIH, Committee on Industrial Ventilation, P.O. Box 16153, Lansing, MI 48901. Plate No. VS-101, Abrasive Blast Booth.

19. Industrial ventilation - a manual of recommended practice, 16th Edition, ACGIH, Committee on Industrial Ventilation, P.O. Box 16153, Lansing, MI 48901. Section 6.