

This article was downloaded by: [CDC]

On: 21 February 2012, At: 13:39

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Applied Occupational and Environmental Hygiene

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/uaoh20>

### A Pilot Study on the Effects of Two Ventilation Methods on Weld Fume Exposures in a Shipyard Confined Space Welding Task

Steven J. Wurzelbacher<sup>a</sup>, Stephen D. Hudock<sup>b</sup>, Ova E. Johnston<sup>b</sup>, Leo M. Blade<sup>b</sup> & Stanley A. Shulman<sup>b</sup>

<sup>a</sup> Mitsui-Sumitomo Loss Control, Cincinnati, Ohio

<sup>b</sup> Division of Applied Research and Technology, NIOSH, 4676 Columbia Parkway, Cincinnati, Ohio, 45226

Available online: 30 Nov 2010

To cite this article: Steven J. Wurzelbacher, Stephen D. Hudock, Ova E. Johnston, Leo M. Blade & Stanley A. Shulman (2002): A Pilot Study on the Effects of Two Ventilation Methods on Weld Fume Exposures in a Shipyard Confined Space Welding Task, Applied Occupational and Environmental Hygiene, 17:11, 735-740

To link to this article: <http://dx.doi.org/10.1080/10473220290096069>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

## Case Studies

# A Pilot Study on the Effects of Two Ventilation Methods on Weld Fume Exposures in a Shipyard Confined Space Welding Task

*Dawn G. Tharr, Column Editor*

Reported by Steven J. Wurzelbacher, Stephen D. Hudock, Ova E. Johnston, Leo M. Blade, and Stanley A. Shulman

Current methods to ventilate confined spaces can differ dramatically in contaminant removal efficiency and usually fall into one of two categories: dilution ventilation (DV) or local exhaust ventilation (LEV). Dilution ventilation involves inducing quantities of fresh air to flow into a confined space, often at high velocity. Under certain conditions, this flow creates a mixing or turbulence that can force contaminated air out of any available openings in the space. The main advantage of this method is that it can be applied to a confined space that has only a single opening because the method does not rely on a directional flow to draw contaminants away from the worker. However, DV with resulting turbulence can be very inefficient in removing contaminants from a welder's personal breathing zone (PBZ). Since air flow is not unidirectional, contaminants may be reintroduced into the PBZ before being forced out of the space. This effect can be compounded by worker position and posture if the initial direction of air flow is generally toward the welder's back, creating eddies and mixing of the air in front of the worker.

Local exhaust ventilation (LEV), a more efficient method, is typically enabled by using a fan with a sufficient capture velocity to induce contaminated air to flow through the fan and out of the confined space. In this particular case, LEV is the preferred method, as it takes advantage of the fact that the space is almost completely enclosed, and it ef-

fectively turns the workspace into a ventilation hood that surrounds the welder.

Confined space welding presents unique fume and gas exposure control and ergonomic problems. Studies indicate that worker position (in reference to the air flow direction) and posture (in regard to the weld fume plume) significantly affect weld fume exposure. Specifically, ventilation methods that introduce flow toward the back of a welder tend to produce turbulent zones in front of the worker that increase the concentration of fume in the personal breathing zone.<sup>(1,2)</sup> Thus, flow should be directed in the sagittal plane of the worker to minimize this effect. However, in confined spaces, optimal positioning of the worker with respect to ventilation flow is often not possible. Investigators have also suggested that worker posture affects exposure to weld fumes, and that the positions required to minimize exposure are the opposite of those required to reduce static loading and fatigue. Specifically, to reduce exposure, the horizontal distance from a welder's face to the weld arc should be maximized, while the vertical distance above the arc should be minimized.<sup>(3–5)</sup> This is due to the nature of the weld plume, which rises and widens quickly. Consequently, methods to reduce fume exposure by such posturing may not be desirable in terms of ergonomics (which dictates that arm loads should be kept close to the body), and these postures often are not possible in confined spaces where welders are limited in their movements. Welding guns equipped with fume extraction nozzles may appear to offer a possible solution to confined space weld fume extraction, but

these also have ergonomic limitations due to their added weight and are only available for certain weld processes.<sup>(6)</sup>

## Background

A large portion of the welding at shipyards is performed in confined or constrained spaces, due to the modular nature of shipbuilding. Subassemblies are constructed at various points in the line and are joined as the process progresses. Automated welding is performed in many instances on larger components to join flat steel plates. The process is also scheduled so that the majority of manual welding is performed before subassemblies are enclosed. However, a substantial amount of manual welding is still required in the confined spaces of the subassemblies. A typical confined space hull assembly is shown in Figure 1.

The ventilation methods and weld processes utilized for confined spaces vary throughout the shipyard. The ventilation method that the shipyard employed on the hull sections was DV, which involved forcing air into the hull cell from the open end with a venturi air horn (Universal UT 9220 3" Air Mover, MSA, Pittsburgh, PA) supplied by a compressed air line. Previous research<sup>(7)</sup> indicated that the projected minimum time-weighted averages (TWAs) for personal particulate concentrations and area elemental concentrations exceeded the established Threshold Limit Values (TLVs<sup>®</sup>) of the American Conference of Governmental Industrial Hygienists (ACGIH<sup>®</sup>)<sup>(8)</sup> and the Recommended Exposure Limits (RELs) of the National Institute for Occupational Safety and Health (NIOSH)<sup>(9)</sup> for both



**FIGURE 1**  
Typical confined space hull assembly.

the stick and wire weld processes for welding in the individual hull cells, which measure approximately 2 feet high by 2 feet wide by 16 feet in length.

In response to the previous study, shipyard engineers changed the design of the hull cells to include an eight-inch circular opening in the forward bulkhead between each opposing cell for the purpose of improving ventilation. New electric ventilation fans (RAMFAN UB20-ED 7002, Euramco Safety, Inc., Spring Valley, CA) were also purchased to replace the compressed air-powered venturi horns. These electric fans were thought to be improvements because they have potentially higher and more consistent flow rates than the air horns, operate at a reduced noise level, and reduce the shipyard's dependence on compressed air lines. However, at the time of the present study, these new electric fans were still being used to induce air into the confined space by DV rather than to exhaust the air within the hull cell through the new opening in the bulkhead (LEV).

### Objective

The purpose of this pilot study was to determine the effectiveness of exhausting the hull cells through the newly placed opening in the bulkhead to an adjacent and opposing cell via an air horn placed between the two spaces (LEV), versus inducing air into the hull cell with an electric blower (DV). Based on these findings, recommendations can be made about engineering controls and work practices that may reduce PBZ particulate concentrations and area elemental concentrations.

### Methods and Materials

#### Subjects

Three (2 male, 1 female) volunteer welders were studied as they performed confined space stick welding as part of their typical work shift under varying conditions of ventilation. All subjects were employees of the shipyard. These individuals had achieved certification for at least second-class welding with the stick electrode process. Welders were not excluded from participating based on race or ethnic background.

#### Study Design

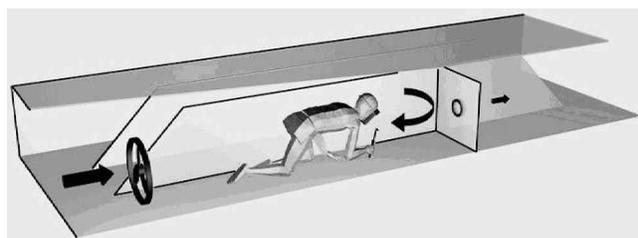
A randomized block design was used to compare the effectiveness of the ventilation methods in terms of minimizing personal particulate concentrations (total weight and elemental, milligrams per cubic meter [ $\text{mg}/\text{m}^3$ ]). Welders at the shipyard typically complete the welding on 10 hull cells per day, with each task lasting for approximately 20 minutes. Since sampling was conducted during the subjects' actual working shifts, the number of hull cells completed during this study by each welder ranged from 6 to 10 cells, and the time to complete each

task ranged from 11 to 27 minutes (mean of 19.5 minutes). The ventilation method was alternated, using one method per hull cell, according to randomized pairing. All pair-wise sampling for each subject was conducted on the same side of the hull section to minimize the possible effects of wind direction and speed. Air sampling time was operationally defined to begin the moment the weld arc was first struck inside of a given cell, and to end when the last arc for that hull cell was disengaged.

Each subject wore the required personal protective equipment deemed necessary for stick welding in a confined space by the shipyard. This included a welding helmet, insulated overalls, gloves, UV protective face shield, and personal respirator (3M 6300 disposable welding mask with a 3M 2096 P-100 particulate filter, 3M, St. Paul, MN). In addition, all welding was conducted in accordance with safe welding guidelines as recommended by the American Welding Society.<sup>(10)</sup> Mild steel stick electrodes (Lincoln Electric Co., Cleveland, OH) were used for all trials (16-inch, E7024-AWS Class, *Jetweld* brand, AC operated at a current range of 350–450 amps) with *Tweco* electrode holders (Model A-38-HD). Subjects were also videotaped to monitor the relationships between welder posture/position, welding fume exposure, and ventilation method usage.

#### Description of Variables

*Dilution ventilation (DV)*. This condition consisted of an electric fan that directed outside fresh air into the confined space (see Figure 2). This fan was typically positioned at the bottom of



**FIGURE 2**  
Shipyard dilution ventilation.

the entrance to the confined space and was rated to produce 980 cubic feet per minute (cfm) in free air. On-site air flow measurements were also taken on the side of the hull assembly directly opposite from the cell in which the electric fan was currently operating immediately prior to the start of each trial. These readings indicated that the fan produced a mean flow rate through the joined cells of  $193 \pm 3$  cfm. Two electric fans were used during the course of the trials: Subjects II and III used the same unit, while Subject I used a second unit.

**Local exhaust ventilation (LEV).** This condition consisted of exhausting the hull cell space through the newly placed hole in the bulkhead to an adjacent cell via an air horn (Universal UT 9220 3" Air Mover) placed between the two spaces (see Figure 3). Two air horns were used during the course of the trials: Subjects II and III used the same unit with a 90-foot (5/8-inch inside diameter) compressed air line, while Subject I used a second unit with a 30-foot (5/8-inch inside diameter) compressed air line. Prior to the start of each trial, the centerline velocities for both horns were measured on-site to be in the range of 6,000–7,000 feet per minute (fpm) (approximately 1,000 cfm). On-site air flow measurements were also taken on the side of the hull assembly directly opposite from the cell in which the air horn was currently operating prior to the start of each trial. These readings indicated that the air horn setup #1 (Subjects II and III) produced a mean flow rate through the joined cells of  $977 \pm 34$  cfm, while air horn setup #2 (Subject I) produced a mean flow rate through the joined cells of  $541 \pm 9$  cfm. Trials for Subject I were

later excluded from some statistical analysis due to the poor performance of the air horn setup caused by a sand blockage in the inlet of this apparatus.

#### *Description of Air Sampling Measurements/Standards and Statistical Methods*

**Personal air sampling.** The method used to conduct total particulate personal sampling was the NIOSH Manual of Analytical Methods (NMAM) Method 0500—Particulates Not Otherwise Regulated,<sup>(11)</sup> which is similar to the standard method recommended by the American Welding Society (AWS)<sup>(12)</sup> to determine fume generation rate (g/min). However, results were reported as  $\text{mg}/\text{m}^3$  units to compare to recommended TWAs for total weld fume established by ACGIH.<sup>(11)</sup> Specifically, total particulate sampling was conducted using a PBZ filter placed on the lapel of the welder's clothing. A sampling rate of 1 liter per minute (L/min) was established using MSA Personal Sampling Pumps (*Escort* Model, MSA, Pittsburgh, PA), which were calibrated using an SKC Ultraflo Calibrator (Model #709, SKC, Eighty Four, PA). Field blank samples were also gathered. In the event of pump failures, sampling time was reduced as determined to be appropriate. Failed or corrupted filters were excluded from further analysis. Samples were then analyzed for total weight by gravimetric analysis by an independent analytical laboratory. For one randomly chosen pair of ventilation methods from each subject, metal fume constituents were also determined by NIOSH Method 7300,<sup>(13)</sup> which utilizes an Inductively Coupled Plasma (ICP) El-

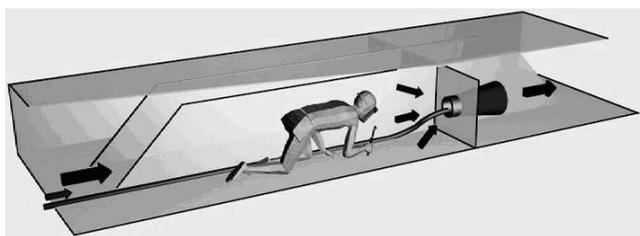
emental Scan that is also recommended by the AWS for this purpose.<sup>(14)</sup>

Raw concentrations (total particulate and elemental,  $\text{mg}/\text{m}^3$ ) for each condition were calculated by dividing the total sample weight by the total volume sampled and subtracting the nominal concentrations registered by the field blanks. Percent changes,  $(1 - [\text{Estimated Geometric Mean of Local Exhaust Ventilation Concentration}/\text{Estimated Geometric Mean of Dilution Ventilation Concentration}]) * 100$ , between pair-wise methods were calculated. Statistical differences in raw concentrations between pair-wise ventilation methods were then assessed for Subjects II and III using a Student's t-test. The analysis was carried out on the natural log scale because Subject III's exposures were about twice as high as Subject II's exposures. Ratios of concentrations for the workers were more nearly constant than differences, and the log scale is most appropriate for ratios. Subject I was excluded from these comparisons because the LEV air horn setup that was used for this subject produced a substantially lower mean flow rate ( $541 \pm 9$  cfm) through the joined cells than the mean flow rate ( $977 \pm 34$  cfm) produced by the air horn setup used by Subjects II and III. This was found to be due to a sand blockage in the air inlets of this apparatus. It is not known how common a sand blockage in the air horn apparatus was throughout the shipyard, as only two items were examined. The results of the statistical analyses are to be interpreted as applying only to these workers within the pilot study, since the results of two workers seems too few to generalize to a larger population.

## Results

### *Total Particulate Results*

For Subject I, the LEV method was associated with an average total particulate concentration of  $69.81 \text{ mg}/\text{m}^3$  (standard error = 9.08, geometric mean =  $68.52 \text{ mg}/\text{m}^3$ ), whereas the DV method resulted in an average total particulate concentration of  $66.23 \text{ mg}/\text{m}^3$  (standard error = 2.90, geometric mean =  $66.04 \text{ mg}/\text{m}^3$ ). Based on geometric



**FIGURE 3**  
Shipyard local exhaust ventilation.

means, the LEV method averaged a 4 percent higher concentration of particulates than the DV method. For Subject II, the LEV method resulted in an average total particulate concentration of  $8.15 \text{ mg/m}^3$  (standard error = 1.27, geometric mean =  $7.72 \text{ mg/m}^3$ ), while the DV method was associated with an average total particulate concentration of  $30.32 \text{ mg/m}^3$  (standard error = 5.30, geometric mean =  $28.45 \text{ mg/m}^3$ ). This corresponded to a 73 percent reduction (based on geometric means) of total particulate by the LEV method over the DV method. For Subject III, the LEV method was associated with an average total particulate concentration of  $16.02 \text{ mg/m}^3$  (standard error = 5.91, geometric mean =  $12.86 \text{ mg/m}^3$ ), whereas the DV method resulted in an average total particulate concentration of  $57.80 \text{ mg/m}^3$  (standard error = 2.46, geometric mean =  $57.69 \text{ mg/m}^3$ ). This corresponded to a 78 percent reduction (based on geometric means) of total particulate by the LEV method over the DV method. The PBZ total particulate results are presented in Table I.

The data from Subject I was dropped from further analysis due to the apparatus malfunction as previously mentioned. A Student's t-test (at the .05 significance level) was conducted to analyze the pairwise differences in PBZ particulate concentrations between the LEV and DV

methods for Subjects II and III. The overall reduction due to the LEV method, using Subjects II and III only, was calculated to be 75 percent (two-sided confidence limits = 58%, 85%).

#### Elemental Scan (ICP) Results

Raw concentrations ( $\text{mg/m}^3$ ) for the elements found to be substantially present were determined (see Table II). These elements included aluminum, copper, iron, lithium, manganese, titanium, and zinc oxide. A statistical analysis of the reduction of these elemental concentrations due to the LEV method was not performed because only one pair of methods was analyzed by ICP for each subject. However, overall trends for the elemental results tended to mirror those for the total particulate results.

For Subject I, the overall percent change in raw concentrations (of analytes that were quantifiable) between methods was -42 percent, meaning that the LEV method averaged 42 percent higher concentrations than the DV for the elements of copper, iron, manganese, titanium, and zinc oxide. For Subject II, raw elemental concentrations were reduced by an average of 76 percent for the elements of iron, manganese, titanium, and zinc oxide by using the LEV method over the DV method. For Subject III, raw elemental concentrations were reduced by an average of 53 percent for the ele-

ments of iron, manganese, and zinc oxide by using the LEV method over the DV method.

## Discussion

### Ventilation Method Comparison

The LEV method reduced total particulate concentrations ( $\text{mg/m}^3$ ) by 75 percent over the DV method for subjects using the well-maintained air horn. These results are not surprising given that the flow rates achieved through the confined space were up to five times greater with the LEV ( $977 \pm 34 \text{ cfm}$ ) than with the DV method ( $193 \pm 3 \text{ cfm}$ ). The improvement with the LEV method was hypothesized to occur since this method effectively turns the hull cell into a ventilation hood that completely encloses the welder, thereby enhancing the capture of particulates. Also, DV in such a confined space was thought to be less effective because it does not evacuate fume efficiently from the welders' PBZ due to worker positioning effects. However, the results of this pilot study also indicate that the efficiency of either method depends greatly on equipment maintenance and work practices. When all three workers are included in the analysis, the LEV method reduced total particulate concentrations, regardless of work posture or functionality of air horn, by 49 percent (two-sided confidence interval = 22%, 67%).

**TABLE I**  
Personal sample total particulate results

	Raw concentrations ( $\text{mg/m}^3$ )								
	Subject I			Subject II			Subject III		
	LEV	DV	% change	LEV	DV	% change	LEV	DV	% change
Sample 1	n/a	63.95	n/a	11.24	45.79	75	4.56	58.65	92
Sample 2	52.08	74.62	30	9.70	22.24	56	19.18	61.57	69
Sample 3	75.24	65.00	-16	9.51	16.96	44	24.31	53.18	54
Sample 4	82.10	61.34	-34	4.71	38.87	88			
Sample 5				5.61	27.76	80			
Mean	69.81	66.23		8.15	30.32		16.02	57.80	
Standard error*	9.08	2.90		1.27	5.30		5.91	2.46	
Geometric mean	68.52	66.04	-4	7.72	28.45	73	12.86	57.69	78

$\text{mg/m}^3$  = milligrams of particles per cubic meter of air.

\*Standard error = standard deviation/[number of measurements]<sup>0.5</sup>).

**TABLE II**  
Elemental scan (ICP) results

Analyte	Raw concentrations (mg/m <sup>3</sup> )								
	Subject I			Subject II			Subject III		
	LEV	DV	% change	LEV	DV	% change	LEV	DV	% change
Aluminum	0.17#	0.18#		ND (<3)	ND (<3)		ND (<3)	0.28#	
Copper	0.06	0.04	-50	ND (<0.2)	0.013#		ND (<0.2)	0.08	
Iron	19.55	13.98	-40	1.59	7.27	78	4.96	10.35	52
Lithium	0.006#	0.002#		ND (<0.1)	ND (<0.1)		0.002#	ND (<0.1)	
Manganese	4.26	3.20	-33	0.43	2.14	80	1.64	3.29	50
Titanium	0.69	0.43	-60	0.09	0.33	73	ND (<0.2)	0.009#	
Zinc oxide	20.42	16.24	-26	3.46	13.69	75	5.95	14.12	58
Overall percent mean change (of analytes that are quantifiable)			-40	Mean		76	Mean		53

mg/m<sup>3</sup> = milligrams of contaminant per cubic meter of air.

ND = not detected.

# represents estimated concentration value, based on an analytical result below the reliable limit of quantification.

No standard errors are given, since all determinations on a subject are highly correlated and cannot be treated as a random sample.

The effect of equipment maintenance on a given method's efficiency was so substantial that Subject I was later excluded from statistical comparisons. The LEV air horn setup that was used for this subject produced a significantly lower mean flow rate ( $541 \pm 9$  cfm) through the joined hull cells than the mean flow rate ( $977 \pm 34$  cfm) produced by the air horn setup used by Subjects II and III. This inconsistency between air horns was not immediately detected because centerline velocities for both horns were measured on-site to be in the range of 6,000–7,000 fpm. It was only after air flow measurements were also taken during trials on the side of the hull assembly directly opposite from the cell in which the air horn was currently operating that the inconsistency was noted. A decision was made to continue the use of the problem air horn, but to restrict its use to Subject I. After Subject I's trials, the cause of the diminished air flow for this air horn was found to be a sand blockage in the air inlets.

The efficiencies of both ventilation methods were also greatly affected by individual work practices of the subjects within this pilot study. Subjects II and III both generally started welding in the

rear of the hull cell, and then backed out. By facing the bulkhead in this manner, the local exhaust horn always remained in front of the welder, and fumes were immediately extracted without being recirculated in the PBZ. On the other hand, Subject I tended to start welding on the outside of the cell, and then backed in. In this manner, this welder often had his back to the local exhaust horn, and fumes were drawn through the PBZ. Consequently, the nearly sixfold increase in average total particulate concentration for the LEV method for Subject I compared with the other welders ( $69.81$  mg/m<sup>3</sup> versus  $8.15$  mg/m<sup>3</sup> and  $16.02$  mg/m<sup>3</sup>) was probably a result of both the reduced flow rate of the air horn used and the work practice of facing out. The importance of which direction the welder was facing is also supported by the fact that Subject III occasionally faced out, too, and this subject had the next highest average total particulate concentration for the local exhaust method, at  $16.02$  mg/m<sup>3</sup>.

The DV method also tended to be used less consistently by all welders than the LEV method. With the LEV, the welder first crawled into the hull cell and placed

the air horn in the hole between the adjacent cells. Once the horn was in place, the welder would then proceed with his or her welding tasks, while the horn ventilated the space continuously in an unobtrusive manner. However, with the DV, the welder had to constantly readjust the position of the electric fan, which was placed obtrusively at the entrance to the cell. When the welder was working at the open end of the cell, the fan was often positioned sideways or placed in the next adjoining cell where it would not be in the way. In both of these instances, the fan was not being used effectively. As well, during welding in the inside sections of the cell, the fan would often get inadvertently knocked over or turned sideways by the weld cables or the welder's legs.

Another work practice that affected the efficiencies of both methods was the manner in which the welders completed the welding tasks on each hull cell. Welders sometimes completed an entire cell section before moving on to the next cell. Other times, the welders finished welding the open ends of select hull cells after they had finished welding the insides of the other cells. Often, no ventilation was operating when the

worker finished these ends. Overall, the LEV method resulted in lower concentrations than the DV method, regardless of welding task technique. However, the most effective way to reduce concentrations was to complete the cell as a unit (finishing the end immediately after the inner space) while the LEV (the air horn) was still attached to the bulkhead of the hull cell.

### Conclusions

The results of a Student's t-test indicated that the LEV method was associated with significantly lower ( $p < 0.05$ ) PBZ total particulate concentrations than the DV method. The efficiency of the LEV method depended greatly on work practices and equipment maintenance. Total particulate concentrations were lower for welders who start welding in the rear of the hull cells and then back out while facing the air horn. Another way to minimize particulate exposure is for welders to complete the cell as a unit (finishing the end immediately after the inner space) while the LEV (the air horn) is still attached to the bulkhead of the cell. Inlets on air horns should be checked regularly for blockages and cleaned as necessary to maintain proper air flow. The LEV method may also be used by substituting an electric fan for the air horn used in this study. In that case, the fan should be aligned in front of the hole in the bulkhead so that air flow is directed to the adjacent and opposite cell.

### REFERENCES

- George, D.K.; Flynn, M.R.; Goodman, R.: The Impact of Boundary Layer Separation on Local Exhaust Design and Worker Exposure. *Appl Occup Environ Hyg* 5(8):501-509 (1990).
- Kim, T.; Flynn, M.R.: Airflow Pattern Around a Worker in a Uniform Freestream. *Am Ind Hyg Assoc J* 52(7): 187-296 (1991).
- Farwer, A.: Air Pollutants in Shielded Arc Welding: Relationship Between Their Formation and the Concentration in the Breathing Zone. *Schweissen Schneiden* 34(2):97-101 (1982).
- Grosse-Wordemann, J.; Stracke, E.: Relationships Between Exposure to Fumes when Welding and Welding Position Is Dictated by Design Considerations. *Schweissen Schneiden* 34(2):109-112 (1982).
- Pomaska, H.: The Effects of Welding Conditions on the Air Polluting Substances During Shielded Arc Welding. *Schweissen Schneiden* 34(2):102-107 (1982).
- Beauchamp, Y.; Marchand, D.; Galopin, M.; et al.: Impact of the Use of Welding Guns Equipped with a Fume Extraction Nozzle on Muscular Activation, Psychophysical Perception, and Quality of Welded Joints. In: *Advances in Occupational Ergonomics and Safety II*. B. Das, W. Karwowski, Eds., pp. 197-200. IOS Press and Ohmsha (1997).
- Wurzelbacher, S.J.; Hudock, S.D.; Lowe, B.D.; et al.: In-Depth Survey Report: The Effect of Weld Process and Ventilation Method on Physical Work Load, Weld Fume Exposure, and Weld Performance in a Confined Space Welding Task. EPHB Report Number 229-11d. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Applied Research and Technology, Engineering and Physical Hazards Branch, Cincinnati, OH (2000).
- American Conference of Governmental Industrial Hygienists (ACGIH®): Threshold Limit Values (TLVs®) for Chemical Substances and Physical Agents. ACGIH®, Cincinnati, OH (2002).
- National Institute for Occupational Safety and Health (NIOSH): NIOSH Pocket Guide to Chemical Hazards and Other Databases. DHHS (NIOSH) Publication No. 99-115. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, NIOSH, Cincinnati, OH (1999).
- American Welding Society (AWS): Welding Handbook. 8th Edition; Volume 1:352; L. Conner, Ed. AWS, Miami, FL (1987).
- National Institute for Occupational Safety and Health (NIOSH): Particulates Not Otherwise Regulated, Total: Method 0500. In: *NIOSH Manual of Analytical Methods (NMAM)*. 4th edition. M.E. Cassinelli; P.F. O'Connor, Eds., DHHS (NIOSH) Publication No. 94-113. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, NIOSH, Cincinnati, OH (1994).
- American Welding Society (AWS): Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes. AWS F1.2:1999. AWS, Miami, FL (1999).
- National Institute for Occupational Safety and Health (NIOSH): Elements by ICP: Method 7300. In: *NIOSH Manual of Analytical Methods (NMAM)*, 4th edition. M.E. Cassinelli, P.F. O'Connor, Eds. DHHS (NIOSH) Publication No. 94-113. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, NIOSH, Cincinnati, OH (1994).
- American Welding Society (AWS): Methods for Analysis of Airborne Particulates Generated by Welding and Allied Processes. AWS F1.4-97. AWS, Miami, FL (1997).

---

**EDITORIAL NOTE:** Steven J. Wurzelbacher is currently with Mitsui-Sumitomo Loss Control in Cincinnati, Ohio. Stephen D. Hudock, Ova J. Johnston, Leo Blade, and Stanley A. Shulman are with the Division of Applied Research and Technology of NIOSH. More detailed information is available by contacting Stephen D. Hudock, NIOSH, Division of Applied Research and Technology, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone: (513) 533-8183; fax: (513) 533-8596.

---

### Disclaimer

Mention of company names and/or products does not constitute endorsement by the Centers for Disease Control and Prevention (CDC).