IN-DEPTH SURVEY REPORT:

Control Technology Assessment for the Welding Operations

at

Cleveland Range, Inc. Cleveland, Ohio

REPORT WRITTEN BY
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SUMMARY

The Engineering Control Technology Branch of the National Institute for Occupational Safety and Health is currently conducting a study of welding operations and workers' exposures to welding fumes The goal of this study is to identify, observe, and evaluate engineering control measures which may reduce the amount of fume a worker is exposed to during welding At the conclusion of this study, information on effective control technology will be disseminated to the welding community At the site described in this report, fume extraction guns were used to control some of the welders' exposures to welding fume Welding processes evaluated during this field survey included gas metal arc welding, gas tungsten arc welding, and flux-cored arc welding Flux-cored arc welding was performed on boilerplate (carbon) steel using a carbon dioxide shielding gas The fume extraction guns were only used for flux-cored welding during the study The gas metal arc welding and gas tungsten arc welding techniques were used on stainless steel, with a carbon dioxide-based shielding gas for the former, and an argon-based shielding gas for the latter No ventilation was used with these techniques

Gravimetric analysis of filter samples collected for total welding fume (total particulate) on the welders showed that the gas tungsten arc welders had the lowest exposures, while the flux-cored arc welders had the highest levels One sample from a flux-cored arc welder exceeded the OSHA PEL-TWA for total particulate which is set at 15 mg/m^3 This welder did not have the ventilation to his fume extraction gun turned on Even with the fume extraction guns in use, three out of the four flux-cored arc welders still exceeded the ACGIH's TLV-TWA of 5 mg/m^3 for welding fume during at least one of the sampling days

Elemental analyses of the filters revealed that none of the fume constituents analyzed were in excess of their respective OSHA PEL levels However, several welders did have iron, manganese, or nickel exposures above the NIOSH REL or the ACGIH TLV levels Among the flux-cored arc welders, all four exceeded the TLV level of 0 2 mg/m^3 for manganese, one exceeded the TLV level of 5 mg/m^3 for iron oxide, and one exceeded the REL level of 0 015 mg/m^3 for nickel The iron oxide exposure was measured when the ventilation to the fume extraction guns was turned off, however, the other exposures were measured with the ventilation operational Among the gas metal arc welders, both welders' exposures exceeded the REL level of 0 015 mg/m^3 for nickel The gas tungsten arc welders did not have any measurable exposures

From the data, the use of the fume extraction guns did not appear to effectively control the welding fumes Although the ventilation system may be capable of lowering the fume levels, it did not always control the worker's exposure to below the recommended exposure limits The ability of the extraction system to capture the welding fumes appeared to be adversely affected by the use of overhead and standing fans in the welding areas Additionally, the welders were able to manipulate the gun ventilation by adjusting the collar attachment, usually the ventilation was "turned down" so that the shielding gas was not exhausted away before the weld was completed This potentially decreased the effectiveness of the fume extraction system as well

INTRODUCTION

Over the past twenty years, the National Institute for Occupational Safety and Health (NIOSH) has recognized the importance of preventing potential health hazards associated with fumes and gases generated during welding operations (see Appendix A), however, no comprehensive study of control technology for welding operations has been conducted since the late seventies As such, the Engineering Control Technology Branch (ECTB) of NIOSH is currently conducting a study to evaluate the effectiveness of engineering control measures in reducing welding fume exposures This welding assessment study was initiated for several reasons First, even with advances in control technology, welders continue to be exposed to hazardous welding fumes and gases [1] Second, the continual development and implementation of new welding processes, techniques, and materials can result in unidentified and uncontrolled health hazards Third, many welding operations are small shops that may not have access to current technology for the control of welding emissions, this project responds to the NIOSH small business initiative which identifies welding shops as one of the top ten hazardous small businesses, in terms of occupational health risks [2] Finally, as it is likely that welding will be a high priority for OSHA over the next few years,[3] industry will need timely research on engineering technology for the control of welding fumes and gases

Many shops use a combination of ventilation and respiratory protection equipment to control the amount of fumes (and gases) the welder is exposed to during welding operations If the ventilation system does not adequately control the fumes, the welder often relies heavily on the respirator for protection against potential health hazards Ideally, respiratory protection should be used only as a last resort against welding fumes, and only when a respirator protection program is in place It is unclear whether adequate respiratory protection programs are common in welding shops Therefore, the goals of this assessment study are to identify effective ventilation systems, or other engineering control measures, that will protect the welder's health, and to disseminate this information to the welding community To determine which controls are most effective, various systems and processes must be evaluated in the field In this particular study, fume extraction guns were evaluated for their ability to exhaust welding fumes and gases away from the worker's breathing zone, at the point of generation

PLANT AND PROCESS DESCRIPTION

This plant manufactures steam ovens for use in commercial and military kitchens Fabrication of the steam ovens mainly involves straight line welding of stainless and boilerplate (carbon) steel A brazing process, with a tungsten inert gas (TIG) torch, is used to fuse copper tubes inside the gas boilers Boilers which have been nickel plated to prevent corrosion are not welded The three main welding techniques used at this site were solid-wire gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and flux-cored arc welding (FCAW) GMAW and GTAW were used to weld stainless steel (SS) parts, while FCAW was used to weld boilerplate During GMAW, a solid-core wire consumable is continuously fed through a welding gun while a shielding gas is supplied at the gun tip to prevent oxidation of the base metal At this site, the

GMAW shielding gas was a mixture of argon and carbon dioxide The FCAW technique is similar to GMAW except that the wire is hollow and filled with a flux core The flux can be composed of various metals or minerals that promote the weld process by removing impurities and preventing oxidation A carbon dioxide shielding gas was supplied during FCAW In comparison, the GTAW technique uses a welding gun equipped with a fixed, nonconsumable tungsten electrode to generate the arc, and a consumable stainless steel electrode is held near the arc to supply filler metal An argon-based shielding gas was used at this site during GTAW

Most of the plant's 25 welders worked the first shift, the remainder worked the third shift The plant layout is depicted in Figure 1 At the time of the visit, the plant was changing to a Just-In-Time (JIT) process flow to increase productivity The management anticipated some rearrangement of the welding booths to accommodate the new process flow lines All stainless steel welding was eventually to be performed in the area currently occupied by the stainless steel booths, the boilerplate welders would remain at their current location

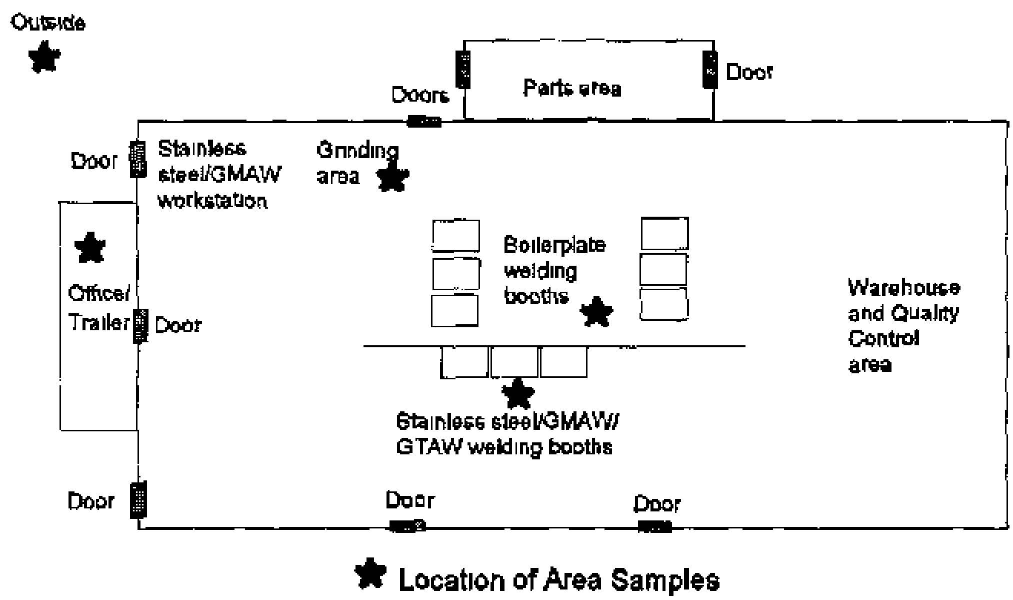

Figure 1 Plant Layout

Overhead fans, wall fans, and free-standing fans were found throughout the plant, due to the summer heat and humidity during the survey, every welder had one in his work area Doors were open to the outside A 5-foot long, enclosed walkway connected the trailer door to the plant door Both doors were kept closed at all times when not in use The ceiling in most parts of the plant was over 16 feet high A variety of personal protective equipment was available to the welders cloth arm protectors, leather aprons, welding helmets, disposable fume masks, and hearing protection Most welding stations were surrounded by welding curtains to prevent welder's flash from occurring in nearby workers

VENTILATION SYSTEM

At the time of the study, only the boilerplate welders were using local exhaust ventilation systems, specifically, fume extraction guns These guns were connected to a central vacuum system which exhausted the fumes out of the workplace Many of the welders in the stainless steel booths had previously used fume extraction guns and small suction hoods, however, these units were disconnected from the central vacuum system during the process layout changes Installation of new duct work to these welding stations was in progress, and the local exhaust units for the stainless steel welders were expected to be operable as soon as the JIT process flow was implemented

Prior to the purchase of the fume extraction guns and central exhaust system, the welding operations had an exhaust ventilation system consisting of canopy hoods, moveable exhaust hoods, and electrostatic precipitators Management considered this earlier ventilation system ineffective

The fume extraction guns used in the boilerplate area were purchased approximately 18 months before the study occurred, as such, the welders were well acquainted with handling the guns Two types of fume extraction guns were used One gun, manufactured by Lincoln, incorporated the ventilation directly into the gun design Lines for the shielding gas and exhausted air were encased in a large, single line leading from the gun The second type of gun was a conventional, nonventilated Lincoln model with a Tweco suction attachment connected to the gun nozzle On this model, the shielding gas and exhausted air lines remained separate, the former leading from the gun, the latter from the Tweco attachment Welders could choose to use either gun, depending on their personal preference Welders who felt the all-in-one fume extraction gun was bulky and cumbersome were more prone to use the conventional gun with the suction attachment

The fume extraction guns were each attached to 3-inch diameter ducted drops from the main header of the central exhaust system Air captured by the fume extraction system was filtered through a bag house and exhausted to the outside The filters in the bag house were changed out every two to three weeks by a contractor

HAZARDS AND EVALUATION CRITERIA

The effect of welding fumes and gases on a welder's health can vary depending on such factors as the length and intensity of the exposure, and the specific toxic metals involved Welding processes involving stainless steel, cadmium- or lead-coated steel, or metals such as nickel, chrome, zinc, and copper are particularly hazardous as the fumes produced are considerably more toxic than those encountered when welding mild steel The NIOSH criteria document identifies arsenic, beryllium, cadmium, chromium (VI), and nickel as potential human carcinogens that may be present in welding fumes Epidemiological studies and case reports of workers exposed to welding emissions have shown an excessive incidence of acute and chronic respiratory diseases Welder respiratory ailments can include occupational asthma, siderosis, emphysema, chronic bronchitis, fibrosis of the lung, and lung cancer Epidemiological evidence indicates that welders generally have a 40% increase in relative risk of developing lung cancer as a result of their work [4] Other cancers associated with welding include leukemia, cancer of the stomach, brain, nasal sinus, and pancreas Cadmium poisoning can affect the respiratory system and damage the liver and kidneys A common reaction to overexposure to metal fumes, particularly zinc oxide fumes, is metal fume fever, with symptoms resembling the flu Other health hazards during welding can include vision problems and dermatitis arising from ultraviolet radiation exposures, burns, and musculoskeletal stress from awkward work positions [4] See Appendix B for additional information on potential health hazards from welding

As a guide when evaluating hazards posed by workplace exposures such as those from welding, NIOSH field staff employ environmental evaluation criteria These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects It is, however, important to note that not all workers will be protected from adverse health effects, even if their exposures are maintained below these levels A small percentage may experience adverse health effects due to individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy) In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects, even if the occupational exposures are controlled at the level set by evaluation criteria These combined effects are often not considered in the evaluation criteria Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available

The primary sources of environmental evaluation criteria in the United States that can be used for the workplace are (1) NIOSH Recommended Exposure Limits (RELs), (2) the American Conference of Governmental Industrial Hygienists's (ACGIH) Threshold Limit Values (TLVs), and (3) the U S Department of Labor (OSHA) Permissible Exposure Limits (PELs) The OSHA PELs are required to consider the feasibility of controlling exposures in various industries where the agents are used, the NIOSH RELs, by contrast, are based primarily on concerns relating to the prevention of occupational disease ACGIH Threshold Limit Values (TLVs) refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects ACGIH states that the TLVs are guidelines The ACGIH is a private, professional society It should be noted that industry is legally required to meet only those levels specified by OSHA PELs

In 1989, the OSHA PEL for total welding fume was set at 5 mg/m^3 (5000 $\mu g/m^3$) as an 8-hour time-weighted average (TWA), however, this limit was vacated and currently is not enforceable Since 1989, OSHA has not reestablished a PEL for total welding fume, however, individual PELs have been set for the various constituents which can be found in welding fumes (see

Appendix C) [5] OSHA has also set a PEL for total particulates not otherwise regulated (PNOR) at 15 mg/m^3 as an 8-hour time-weighted average (TWA) A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday Some substances have recommended short-term exposure limits (STEL) or ceiling values that are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures

The ACGIH has set a TLV-TWA for welding fumes-total particulate (NOC) at 5 mg/m^3 The ACGIH recommends that conclusions based on total fume concentration are generally adequate if no toxic elements are present in the welding rod, metal, or metal coating and if conditions are not conducive to the formation of toxic gases [6] NIOSH indicates that it is not possible to establish an exposure limit for total welding emissions since the composition of welding fumes and gases vary greatly, and the welding constituents may interact to produce adverse health effects Therefore, NIOSH suggests that the exposure limits set for each welding fume constituent should be met (see Appendix C) However, it was noted in the NIOSH criteria document that even when welding fume constituents were below the PELs, there was still excesses in morbidity and mortality among welders As such, NIOSH recommends that welding emissions should be controlled, with current exposure limits considered to be upper limits [4]

METHODOLOGY

Conventional industrial hygiene air sampling was performed on the welders during the study Samples were collected on closed-faced, 37-millimeter (mm), polyvinyl chloride (PVC) filters, which were analyzed gravimetrically to determine the total welding fume concentration The analysis was conducted according to Method 0500 in the NIOSH Manual of Analytical Methods, 4th edition A known volume of air is drawn through the preweighed PVC filter The weight gain of the filter is then used to compute the milligrams of particulate per cubic meter of air The limit of detection (LOD), or lowest measurable amount, for total particulate for this study was 0 02 mg An element specific analysis was also performed on the filter samples, according to NIOSH Method 7300, to differentiate and quantify the different metal species in the welding fume The LOD and limit of quantitation (LOQ), the level at which the laboratory can confidently report precise results, for each element analyzed are given in Appendix D

Personal samples were collected in the worker's breathing zone using portable pumps set at a flow rate of 3 liters per minute (lpm) Filter cassettes were placed on the lapel of the welders' overalls, just outside of their welding helmets, since the purpose of the study was to evaluate the control effectiveness of the ventilation, not the personal protective gear To prevent overloading, the filters were occasionally changed out during the shift and replaced with new filters Personal sample filter results were combined using time-weighted averaging techniques to determine the workers' full-shift exposures These results are the workers' average exposure while being sampled Zero exposures during nonsampling periods (such as lunch breaks) were not included Area samples were also collected using portable sampling pumps set at a rate of 3 lpm The samples were located in the grinding, boilerplate, and stainless steel work areas Base line area samples were also obtained inside the air-conditioned trailer and just outside the plant The outside plant sample was hung on a cyclone fence at about eye level

Gases from the welding operation were monitored manually using direct-reading colorimetric indicator tubes and a bellows pumps Sampled gases included carbon monoxide, ozone, and nitrogen dioxide

The fume extraction system was assessed by measuring capture velocities using a hot wire anemometer This instrument measures air velocity in feet per minute (fpm) Capture velocities are measured to determine the ability of the system to remove welding fumes at certain distances away from the fume generation source The capture velocity is the velocity necessary to overcome opposing air currents and cause the welding fume to be exhausted Work methods regarding the use of the ventilation systems were also observed, such as differences in positioning the "choke" collar on the fume extraction guns This collar allows the welder to increase or decrease the amount of ventilation In addition, airflow patterns around the workers during welding were observed using smoke tubes and aspirators From this, an understanding of how air contaminants are transported into the worker's breathing zone can be developed Smoke tubes were also used to observe airflow patterns at the plant entrance ways

RESULTS AND DISCUSSION

Although the focus of this study was on welding fume exposures, plant management was also interested in determining exposure levels when grinding, particularly for stainless steel work As such, sampling data for the grinding operations were also collected and included in the tables

GRAVIMETRIC ANALYSIS (TOTAL WELDING FUME)

The personal sampling data for total welding fume concentrations were analyzed with respect to the welding process and the sample location, and exposure differences between individual welders were also noted The area sampling data was analyzed with respect to sampling location Individual sampling data used to derive Tables 1-4 can be found in Appendix E

Personal Welding Fume Levels as Related to Welding Process

Based on information from the plant and other welding studies, the FCAW process was expected to produce the most fume and the GTAW process was expected to produce the least This assumption was verified upon analysis of the data (Table 1) Visually, it was also apparent that the flux-cored process was the heaviest fume producer, regardless of whether or not the welders used the fume extraction gun ventilation

Table 1 Total Particulate Mean Concentrations by Welding Process

Welding Process	N	Mean (mg/m³)	Std Dev (mg/m³)
Flux-cored (Boilerplate)	21	8 67	11 5
GMAW (SS)	10	1 51	0 64
GTAW (SS)*	10	0 16	0 07

* This includes one sample which was collected on boilerplate Also, one sample which was collected during both GMAW and GTAW was not included in this table

The highest total particulate concentration during the study was measured during unventilated, flux-cored arc welding of boilerplate steel Eliminating this exposure from the data analysis (since it was unusual to have the ventilation off during this operation) would have resulted in a mean concentration of 6 3 mg/m³ for flux-cored welding, with a standard deviation of 4 9 Thus, the flux-cored results showed average personal exposures to be more than four times the exposures for GMAW The second highest total particulate concentration of the study was measured during ventilated, flux-cored arc welding of boilerplate steel

Personal Welding Fume Levels as Related to Sample Location

Overall, the boilerplate welders had the highest average exposure (Table 2) This is logical as these welders perform flux-cored arc welding The welder at the stainless steel workstation had a higher average exposure than the welders in the stainless steel line This was attributed to the fact that only gas metal arc welding was performed at the workstation, while welders in the stainless steel line area performed GTAW, in addition to GMAW, which resulted in a lower overall average exposure

Table 2 Personal Total Particulate Mean Concentrations by Sample Location

Sample Location	N	Mean (mg/m³)	Std Dev (mg/m³)
Stainless Steel Workstation (GMAW)	6	1 39	0 64
Boilerplate (FCAW)*	22	8 29	11 4
Stainless Steel Line (GMAW/GTAW)	14	0 61	0 76
Grinding	2	0 37	0 07

* This includes one sample that was collected during GTAW of the boilerplate

Personal Welding Fume Levels as Related to Individual Welders

Full-shift exposures for the welders for each day of sampling are shown in Table 3

Table 3 Workers' Full-Shift Total Particulate Exposures

Worker	Welding Technique	N	Day 1 (mg/m³)	N	Day 2 (mg/m³)	N	Day 3 (mg/m³)
A	GMAW	2	1 22	2	1 08	2	2 20
B	GTAW	2	0 12	1	0 18	1	0 09
C	GTAW	2	0 10	1	0 13	1	0 21
D	GMAW/GTAW	1	1 43	2	1 04	3	1 03
E	FCAW	2	33	3	3 28	3	6 66
F	FCAW	2	10	4*	4 34	3	7 05
G	FCAW	2	7 25	0	-	0	-
H	FCAW	1	2 96	0	-	2	1 37
I	GRINDING	0	-	0	-	2	0 54

* The samples collected on Worker F on Day 2 were actually comprised of 3 FCAW and 1 GTAW

The highest total particulate exposure was found to occur on Day 1 on Worker E, a boilerplate welder During this sampling day, Worker E performed flux-cored welding without the ventilation system attached (unusual occurrence), resulting in an exposure level above the OSHA PEL of 15 mg/m^3 for total particulate (welding fume) On the same day, two other boilerplate welders, Workers F and G, had exposure levels above the ACGIH TLV-TWA level of 5 mg/m^3 for total welding fume Exposures in excess of the TLV were also found on Day 3 for Workers E and F Information gathered on work practices in the boilerplate area may help to explain some of these results Worker G was observed to use a Lincoln welding gun with the Tweco fume extraction system attached to it The collar on the gun could be moved up and down to change the exhaust level On the first day of sampling, Worker G noted that Worker F positioned his welding collar high to reduce the exhaust ventilation level Worker F indicated he was concerned that the ventilation would remove the shielding gas and interfere with the weld Worker G was also concerned about possible interference from the ventilation, he tried to circumvent any problems by increasing the amount of shielding gas delivered to the weld area rather than decrease the gun ventilation rate Worker F also noted that the ceiling fan over his workstation seemed to pull the fumes upwards, in opposition to the fume extraction gun which tried to pull the fumes inwards As a result, Worker F felt the two exhaust systems created turbulence in his work area

Among the stainless steel welders, Workers B and C, who performed the GTAW process in adjacent booths, had similar exposures Worker D, who also welded on the stainless steel line, had higher exposures than Workers B and C This was attributed to the fact that Worker D performed both GMAW and GTAW, and the GMAW process was shown to produce more fume than did GTAW (see Table 1) Worker A, who welded on stainless steel at the separate workstation using only GMAW, had an exposure level comparable to Worker D

An interesting, separate analysis is to compare the data collected on Worker E, Day 1 during FCAW (from Table 3) to the mean concentration determined for GMAW (from Table 1) In both cases, no ventilation is used, however, the nonventilated FCAW resulted in approximately 33 mg/m^3, while nonventilated GMAW resulted in approximately 1 5 mg/m^3 This indicates that the FCAW process produced 22 times the amount of total particulate than the GMAW process However, this data is limited since only one set of samples was available on the nonventilated FCAW process

Area Welding Fume Levels

Results showed the background level in the boilerplate area to be highest, and the level inside the air-conditioned trailer to be lowest (Table 4) The higher area sample concentrations in the boilerplate area, as compared to the stainless steel area, agree with the personal sample results

Table 4 Area Total Particulate Mean Concentrations by Sample Location

Sample Location	N	Mean (mg/m^3)	Std Dev (mg/m^3)
Outside Plant	3	0 03	0 03
Inside Trailer	3	0 01	0 01
Boilerplate Area	3	0 64	0 24
Stainless Steel Line Area	4	0 11	0 04
Grinding Area	2	0 29	0 10

Note No sample was obtained for the stainless steel workstation area

ELEMENTAL ANALYSIS RESULTS

The individual sampling data of the elemental analysis is shown in Appendix F To obtain a picture of the overall concentration levels of the welding fume components for the welders at this site, the personal sample concentrations were combined to determine the overall mean and standard deviation for each element The same was done for area samples This data is shown in Appendix G The sampling data were then broken down by welder and by work location for further insight on where the highest welding fume component exposures were occurring for certain elements Results of these analyses are shown in the following tables and are discussed below

Personal Welding Fume Component Levels as Related to Individual Welders

Review of the individual elemental concentrations in Appendix F showed the highest elemental exposures were encountered by Worker E (Mn, Fe, Ni), Worker F (Mn, Ni), Worker G (Mn), and Worker H (Mn) in the boilerplate area (FCAW), Worker A (Ni) at the GMAW stainless steel workstation, and Worker D (Ni) at the stainless steel line (GMAW/GTAW) The exposures for Worker E occurred during both ventilated and nonventilated welding Table 5 presents the workers' full-shift exposures for selected elements during the survey None of the personal full-shift exposure levels exceeded the PELs However, Worker E, a boilerplate welder, exceeded the NIOSH REL (5000 $\mu g/m^3$) and the ACGIH TLV (5000 $\mu g/m^3$) for iron oxide fumes during the first day of sampling when the ventilation on his welding gun was not turned on Worker E and Worker F (also a boilerplate welder) also exceeded the NIOSH REL (1000 $\mu g/m^3$) for manganese on Day 1 During all three days of sampling, Workers E and F exceeded the ACGIH TLV (200 $\mu g/m^3$) for manganese Fellow boilerplate welders, Workers G and H, also exceeded the ACGIH TLV (200 $\mu g/m^3$) for manganese on Day 1 In addition, Workers A, D, and E exceeded the NIOSH REL (15 $\mu g/m^3$) for nickel during all three sampling days It should be noted that the OSHA PEL for nickel is currently under consideration and may be changed to a stricter level in the future

Arsenic was not detected in any of the samples Cadmium, titanium, beryllium, and total chrome were detected in some samples, however, exposures were all below the PELs Several samples were collected specifically to test for the presence of hexavalent chromium, Cr(VI) The test samples were collected on the workers and in the workplace under the same conditions as the industrial hygiene samples The testing was conducted immediately in the field using a colormetric laboratory test kit (EM Quant Chromate Test, EM Sciences, Gibbstown, NJ) No Cr(VI) was detected in the test samples when they were visually compared to the colored lab test strips

Personal Welding Component Fume Levels as Related to Sample Location

Table 6 lists the personal mean concentration and standard deviation for select welding fume components, broken down by the sample location As expected, the stainless steel areas had higher Chromium (Cr) and Nickel (Ni) levels than the boilerplate area, and the boilerplate area had a higher Iron (Fe) level than the stainless steel areas

Table 5 Workers' Full-Shift Exposures for Selected Elements ($\mu g/m^3$)

Worker-Day	N	Al	Cr	Cu	Fe	Mn	Ni	Pb	Ti	Zn
A-1	2	7.9	126	7.3	352	112	49.3	0	0.8	1.9
A-2	2	4.2	100	6.8	316	83.1	46.6	0	0.7	8.6
A-3	2	3.6	184	12.3	556	192	79.1	0	0.7	1.0
B-1	2	3.7	3.7	0.2	14.0	4.0	1.4	0	0.2	0.6
B-2	1	0.7	3.1	0.4	10.8	8.3	1.2	0	0.1	0.2
B-3	1	0.9	2.1	0.3	10.6	2.7	0.8	0	0.1	0.3
C-1	2	5.4	2.8	0.4	13.1	1.9	0	0	0.2	4.0
C-2	1	0.8	2.6	0.2	11.5	3.0	1.2	0	0	0.2
C-3	1	1.5	3.8	0.4	32.9	4.6	2.0	0	0.2	0.4
D-1	1	3.6	100	9.0	348	93.2	57.3	0	0.7	0.7
D-2	2	3.9	76.6	6.5	269	68.8	40.7	0.7	1.0	0.7
D-3	3	1.7	61.1	4.7	218	51.6	35.2	0	1.0	0.6
E-1	2	15.4	15.4	25.0	8580	4370	39.1	14.2	281	33.3
E-2	3	7.6	40.0	5.5	1160	241	23.4	0	83.1	4.9
E-3	3	30.3	26.5	7.7	2040	688	28.2	3.7	129	8.6
F-1	2	20.2	8.3	13.7	2320	1320	11.5	3.8	88.5	12.6
F-2	4	6.3	7.5	8.2	1040	566	5.4	2.1	46.6	5.4
F-3	3	9.8	7.5	8.7	1570	958	7.9	3.8	61.2	8.7
G-1	2	8.7	9.6	11.9	1870	802	10.5	3.2	69.5	9.8
H-1	1	4.1	7.0	3.0	823	354	5.8	0	32.1	5.3
H-3	2	2.5	6.7	3.2	411	72.1	2.5	0	21.3	1.7
I-3	2	11.6	10.6	0.7	55.4	6.8	4.8	0	0.4	0.7

Table 6 Personal Mean Concentrations (µg/m³) for Select Elements by Process Location

Sample Location	N	Al $\bar{x}$ (SD)	Cr $\bar{x}$ (SD)	Cu $\bar{x}$ (SD)	Fe $\bar{x}$ (SD)	Mn $\bar{x}$ (SD)	Ni $\bar{x}$ (SD)	Pb $\bar{x}$ (SD)	Ti $\bar{x}$ (SD)	Zn $\bar{x}$ (SD)
Stainless Steel Workstation	6	4.9 (1.8)	127 (52.1)	8.4 (3.5)	383 (152)	122 (54.5)	55.3 (22.8)	ND	0.7 (0.4)	2.2 (2.1)
Boilerplate	22	13.4 (17.2)	16.1 (15.2)	9.8 (7.9)	2170 (2890)	1020 (1550)	14.2 (13.8)	3.4 (5.3)	92.2 (92.4)	10.0 (11.4)
Stainless Steel Line	14	2.9 (2.1)	38.6 (61.0)	3.1 (4.4)	137 (207)	34.2 (51.4)	21.1 (34.0)	0.2 (0.7)	0.6 (0.7)	1.2 (2.4)
Grinding	2	6.9 (3.9)	7.8 (0.3)	0.5 (0)	44.3 (9.7)	4.9 (0.1)	3.6 (0.3)	ND	0.2 (0.2)	0.6 (0.2)

μ = mean (µg/m³) SD = standard deviation ND = none detected

Area Welding Component Fume Levels

Table 7 lists the area mean concentration and standard deviation for select welding fume components, broken down by sample location. Interestingly, the boilerplate area was found to have the highest levels for almost all the elements analyzed, although grinding resulted in the highest exposure levels for Aluminum (Al), Chromium (Cr), and Nickel (Ni).

Table 7 Area Mean Concentrations for Select Elements by Sample Location (µg/m³)

Sample Location	N	Al $\bar{x}$ (SD)	Cr $\bar{x}$ (SD)	Cu $\bar{x}$ (SD)	Fe $\bar{x}$ (SD)	Mn $\bar{x}$ (SD)	Ni $\bar{x}$ (SD)	Pb $\bar{x}$ (SD)	Ti $\bar{x}$ (SD)	Zn $\bar{x}$ (SD)
Outside Plant	3	ND	ND	ND	3.4 (1.7)	0.9 (0.7)	ND	ND	0.1 (0.1)	0.4 (0.3)
Inside Trailer	3	0.2 (0.3)	0.6 (0.1)	0.1 (0.1)	2.9 (0.8)	0.7 (0.2)	ND	ND	ND	0.3 (0.2)
Boilerplate	3	5.0 (2.7)	4.2 (1.8)	11 (13)	180 (22)	17 (3.8)	1.9 (0.2)	ND	6.6 (0.3)	0.7 (0.5)
Stainless Steel Line	4	1.5 (1.1)	2.1 (0.6)	0.2 (0)	11 (1.9)	2.6 (0.8)	0.9 (0.2)	ND	0.2 (0.1)	0.3 (0.1)
Grinding	2	5.2 (1.3)	6.6 (1.9)	0.6 (0.4)	52 (29)	3.9 (2.4)	3.1 (0.7)	ND	0.2 (0.1)	0.3 (0.1)

μ = mean (µg/m³) SD = standard deviation ND = none detected

DETECTOR TUBE SAMPLING

Detector tube readings were collected for ozone, carbon monoxide, and nitrogen dioxide. Since the base metals did not appear to have undergone any degreasing operations, the presence of phosgene was unlikely and it was not monitored.

Results of grab sampling showed no detection of ozone or nitrogen dioxide in the air. Carbon monoxide was found to exist in the boilerplate area at a concentration of 10 ppm during welding. This level is below the OSHA PEL of 50 ppm (TWA) and the NIOSH REL of 35 ppm (TWA).

VENTILATION MEASUREMENTS

Smoke tubes showed that air was flowing into the plant at most of the doors open to the outside Air flow appeared fairly stagnant at one of the doors in the parts area and at one of the back doors, near the stainless steel line The door across from the boilerplate area was measured to have an air velocity of 100-250 feet per minute (fpm) coming into the plant

Measurements taken on the fume extraction system showed an air velocity of more than 6000 fpm at the duct drop where one of the fume extraction gun was attached (Worker F's workstation) At the time of this measurement, no other fume extraction guns were being used At a distance of 1 inch away from the gun nozzle, a capture velocity of 3500–4000 fpm was measured The ACGIH Industrial Ventilation manual indicates that a velocity of 100-200 fpm should be used to capture welding fumes, with the higher values used for poor conditions such as disturbing room air currents, high toxicity contaminants, and high production/heavy use [7] The manual indicates the capture velocities above 200 fpm may disturb the shielding gas The manual also suggests that the minimum duct design velocities for welding fumes should be between 2000-2500 fpm to prevent settling and plugging of the duct

CONCLUSIONS AND RECOMMENDATIONS

The flux-cored arc welding of the boilerplate steel resulted in the highest welding fume exposures Use of the fume extraction guns appeared to help reduce exposures during boilerplate welding, however, the units did not effectively control all of the welding fume emissions The data analysis showed that nonventilated, boilerplate welding resulted in one full-shift, personal sample exceeding the OSHA PEL for total particulate Out of the four boilerplate welders, three had full-shift total welding fume exposures above the ACGIH TLV during at least one day of the study, even with the ventilation on Review of the fume component exposure data showed that the nonventilated, boilerplate welding resulted in exposure levels above the NIOSH RELs for iron oxide fumes, manganese, and nickel In addition, all four of the boilerplate welders were found to have full-shift exposure levels above the ACGIH TLV for manganese for most of the survey, even with the ventilation on This showed that even when using the fume extraction guns, the boilerplate welders were still being overexposed to welding fume and its components Two of the stainless steel gas metal arc welders were found to have nickel exposures in excess of the NIOSH REL during all three sampling days No ventilation was used during the stainless steel gas metal arc welding

Discussions with the welders showed there to be a major concern among them that the fume extraction guns might be removing the shielding gas along with the welding fume emissions Removal of the shielding gas could increase the likelihood of weld porosity Therefore, to prevent the occurrence of bad welds, some of the welders were moving the collars on the fume extraction guns in order to decrease the amount of air exhausted This may be reducing the effectiveness of the ventilated guns Another way the welders were trying to avoid the possibility of bad welds was to increase the shielding gas flow rate This may be increasing shielding gas usage costs

It was also noted during the survey that the operation of multiple fans in the welding areas may be interfering with the capture efficiency of the fume extraction guns The fans are set up to keep the welder cool in the heat of the summer, however, depending on their orientation, the strong air currents from the fans may affect the ability of the fume extraction guns to easily capture welding fumes In order for the ventilated guns to be used effectively, the use of fans, the level of shielding gas, and the best positioning of the collar on the fume extraction gun should be addressed and discussed with the welders

The results from this study support the argument that excess exposures during welding operations are foremost due to the type of welding operation since certain welding techniques, such as flux-cored arc welding, are likely to produce more fume than other techniques, such as gas tungsten arc welding Secondary factors that affect the exposure amount are the composition of the base metal, work practices, i e , how close the worker gets to the fumes, and the type and effectiveness of local exhaust ventilation Additional factors may include ceiling height and the shape of the object being welded Efforts to control welding fume should focus on processes that generate the most fume At this site, it is recommended that, if possible, the flux-cored arc welding should be replaced with another process technique that generates less fume, or the ventilation system for the boilerplate welders should be improved upon In addition, the ventilation system for the gas metal arc welders should be reconnected to the central vacuum system as soon as possible to lower the exposure levels during the stainless steel welding

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APPENDICES

APPENDIX A: NIOSH BACKGROUND

The National Institute for Occupational Safety and Health (NIOSH) is located in the Centers for Disease Control and Prevention (CDC), under the U S Department of Health and Human Services (DHHS) (formerly the Department of Health, Education, and Welfare) NIOSH was established in 1970 by the Occupational Safety and Health Act, at the same time that the Occupational Safety and Health Administration (OSHA) was established in the Department of Labor (DOL) The OSHAct legislation mandated NIOSH to conduct research and education programs separate from the standard and enforcement functions conducted by OSHA An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemicals and physical hazards

The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering (DPSE) has been given the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness Since 1976, ECTB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to evaluate and document control techniques and to determine the effectiveness of the control techniques in reducing potential health hazards in an industry or for a specific process

During the past twenty years, the National Institute for Occupational Safety and Health (NIOSH) has documented and reported on the need to control worker exposures to the fumes and gases generated during welding operations Much of the attention to welding has been in the form of Health Hazard Evaluations conducted at field sites, however, a few NIOSH reports have focused on control technology These reports are briefly discussed below and can be obtained through NTIS or the NIOSH Publications Office (1-800-35-NIOSH)

In 1974, a research contract report entitled "Engineering Control of Welding Fumes" was published, with the objective of developing design criteria for local ventilation systems to control welding fumes This report identified shielded manual metal arc welding on carbon and stainless steel, and gas-shielded arc welding on carbon steel as processes constituting great health risks to welders A crossdraft table, free-standing hood, and low volume-high velocity fume extraction gun were evaluated to determine the minimum system operating point needed to reduce fumes below threshold limit values (TLVs) [1]

In 1978, the NIOSH booklet "Safety and Health in Arc Welding and Gas Welding and Cutting" included general information on dilution and local exhaust ventilation [2]

In 1979, NIOSH's Division of Physical Sciences and Engineering (DPSE) published the research report "Assessment of Selected Control Technology Techniques for Welding Fumes" This study considered the effect of dilution airflow direction on welder exposures in the field and evaluated a fume extraction gun [3]

In 1988, the NIOSH "Criteria for a Recommended Standard for Welding, Brazing, and Thermal Cutting" was produced In this document, NIOSH recommended that welding emissions be controlled to concentrations as low as feasibly possible using state-of-the-art engineering technology and work practices General guidelines were provided for selecting dilution and local exhaust ventilation systems [4]

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APPENDIX B: POTENTIAL HEALTH HAZARDS

Welding fumes are a product of the base metal being welded, the welding process and parameters (such as voltage and amperage), the composition of the consumable welding electrode or wire, the shielding gas, and any surface coatings or contaminants on the base metal It has been suggested that as much as 95% of the welding fume actually originates from the melting of the electrode or wire consumable [1] The size of welding fume is highly variable and ranges from less than 1 μm diameter (not visible) to 50 μm diam (seen as smoke) [2] Fume constituents may include minerals such as silica and fluorides (used as fluxes) and metals such as arsenic, beryllium (in high copper alloys), cadmium (often used as a rust inhibitor), chromium, cobalt and nickel (in stainless steel), copper (in copper-coated wire), iron, lead (in lead-based paint coatings), magnesium, manganese (in stainless steel, manganese steel), molybdenum, tin, vanadium, and zinc (used to galvanize steel) [3,4,5] Toxic gases such as ozone, carbon monoxide, nitrogen dioxide, and phosgene (formed from chlorinated solvent decomposition) can also be produced [3,4,5] Volatile hydrocarbons can be produced during welding if antispatter sprays, oils, or lanolin (often used during degreasing processes) are present [2]

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4 American Welding Society [1987] Welding Handbook 8th ed , Vol 1, Welding Technology Connor LP, ed Miami, Florida American Welding Society, ISBN 0-87171-281-4

5 Rekus JF [1990] Health Hazards in Welding BodyShop Business *11* 66-77, 188

APPENDIX C: SUMMARY OF SELECTED OCCUPATIONAL EXPOSURE LIMITS

Substance	OSHA PEL-TWA (µg/m³)	NIOSH REL-TWA (µg/m³)	ACGIH TLV-TWA (µg/m³)
Aluminum fume	15 000 (Total) 5000 (Respirable)	5000	5000
Arsenic	10	2 (Ceiling)	10
Barium	500	500	500
Beryllium	2	0.5 (Ceiling)	2
Calcium Oxide	--	2000	2000
Cadmium fume	5	LFC (Ca)	10 (Total) 2 (Respirable)
Cobalt	100	50	20
Chromium, Metal	1000	500	500
Copper fume	100	100	200
Iron Oxide fume	10,000 (as Fe)	5000	5000
Lithium	--	--	--
Magnesium Oxide fume	15000	--	10000
Manganese	5000 (Ceiling)	1000	200
Molybdenum	5000 (Soluble) 15,000 (Insoluble)	--	5000 (Soluble) 10 000 (Insoluble)
Nickel	1000 (change proposed)	15 (Ca)	1000 (change proposed)
Lead	50	100	50
Phosphorus	100	100	100
Platinum	2 (Soluble)	1000 (Metal) 2 (Soluble)	1000
Selenium	200	200	200
Silver	10	10	100
Sodium	--	--	--
Tellurium	100	100	100
Thallium	100	100 (Soluble)	100
Titanium Dioxide	15000	LFC (Ca)	10000
Vanadium Pentoxide fume	100 (Ceiling)	50 (Ceiling)	50
Yttrium	1000	1000	1000
Zinc Oxide fume	5000	5000	5000
Zirconium	5000	5000	5000
Welding fumes	--	LFC (Ca)	5000

LFC=lowest feasible concentration
Ca=NIOSH potential occupational carcinogen

APPENDIX D: ANALYTICAL DETECTION AND QUANTITATION LIMITS

Analyte	LOD (µg/filter)	LOQ (µg/filter)
Silver	0.04	0.13
Aluminum	0.5	1.6
Arsenic	1	3.1
Barium	0.02	0.040
Beryllium	0.02	0.064
Calcium	2	4.1
Cadmium	0.07	0.21
Cobalt	0.2	0.62
Chromium	0.4	1.2
Copper	0.05	0.16
Iron	0.6	1.9
Lithium	0.05	0.17
Magnesium	0.7	2.3
Manganese	0.03	0.091
Molybdenum	0.2	0.43
Sodium	5	17
Nickel	0.4	1.3
Phosphorus	4	11
Lead	0.6	1.8
Platinum	2	4.1
Selenium	0.9	3.0
Tellurium	0.7	2.3
Thallium	2	4.0
Titanium	0.06	0.19
Vanadium	0.2	0.39
Yttrium	0.02	0.041
Zinc	0.07	0.22
Zirconium	0.2	0.36

APPENDIX E: GRAVIMETRIC AIR SAMPLING DATA

Date	Sample #	Welder or Area	Location	Mass (mg)	Flow (lpm)	Time (min)	Volume (l)	Conc. (mg/m³)	Vent?
8-2-95	2203	A	SS station-GMAW	0.99	3	287	861	1.15	No
8-2-95	2110	Area	Outside	0	3	164	492	0	-
8-2-95	2335	C	SS line-GTAW	0.16	3	405	1215	0.13	No
8-2-95	2330	Area	SS line	0.09	3	378	1134	0.08	-
8-2-95	2091	F	Boilerplate	0.16	3	20	60	2.67	Yes?
8-2-95	2347	B	SS line-GTAW	0.22	3	402	1206	0.18	No
8-2-95	2096	E	Boilerplate	1.00	3	71	213	4.69	Yes
8-2-95	2090	A	SS station-GMAW	0.22	3	86	258	0.85	No
8-2-95	2348	D	SS line-GMAW/GTAW	0.38	3	257	771	0.49	No
8-2-95	2098	F	Boilerplate	1.76	3	165	495	3.56	Yes
8-2-95	2095	F	Boilerplate-GTAW	0.08	3	99	297	0.27	Yes?
8-2-95	2341	E	Boilerplate	0.51	3	145	435	1.17	No
8-2-95	2102	D	SS line-GMAW	0.69	3	87	261	2.64	No
8-2-95	2092	Area	Boilerplate	0.57	3	390	1170	0.49	-
8-2-95	2111	Area	Trailer	0.02	3	318	954	0.02	-
8-2-95	2097	E	Boilerplate	1.77	3	117	351	5.04	??
8-2-95	2336	F	Boilerplate	3.20	3	115	345	9.28	Yes
8-1-95	2199	Area	Boilerplate	0.72	3	246	738	0.98	No
8-1-95	2185	C	SS line-GTAW	0.03	3	62	186	0.16	No
8-1-95	2346	D	SS station-GMAW	0.40	3	93	279	1.43	No
8-1-95	2186	E	Boilerplate	11.98	3	72	216	55.46	No
8-1-95	2191	E	Boilerplate	4.51	3	95	285	15.82	No
8-1-95	2189	F	Boilerplate	4.87	3	76	228	21.36	Yes
8-1-95	2202	A	SS station-GMAW	0.53	3	120	360	1.47	No
8-1-95	2184	Area	Grinding	0.68	3	1194	3582	0.19	-
8-1-95	2182	F	Boilerplate	0.46	3	101	303	1.52	Yes
8-1-95	2204	C	SS line-GTAW	0.02	3	104	312	0.06	No
8-1-95	2192	Area	Trailer	0	3	267	801	0	-
8-1-95	2198	B	SS line-GTAW	0.04	3	60	180	0.22	No
8-1-95	2205	Area	SS line	0.11	3	211	633	0.17	-
8-1-95	2195	A	SS station-GMAW	0.06	3	41	123	0.49	No

APPENDIX E: GRAVIMETRIC AIR SAMPLING DATA (Continued)

Date	Sample #	Welder or Area	Location	Mass (mg)	Flow (lpm)	Time (min)	Volume (l)	Conc. (mg/m³)	Vent?
8-1-95	2193	G	Boilerplate	2.34	3	89	267	8.76	Yes
8-1-95	2183	Area	Outside	0.03	3	131	393	0.08	-
8-1-95	2200	B	SS line-GTAW	0.02	3	102	306	0.07	No
8-1-95	2187	H	Boilerplate	0.72	3	81	243	2.96	Yes
8-1-95	2188	G	Boilerplate	1.73	3	98	294	5.88	Yes
8-3-95	2099	Area	Boilerplate	0.59	3	425	1275	0.46	-
8-3-95	2114	Area	Grinding	0.43	3	367	1101	0.39	-
8-3-95	2087	I	Grinding	0.34	3	260	780	0.44	Fans
8-3-95	2117	A	SS station-GMAW	0.62	3	96	288	2.15	No
8-3-95	2125	I	Grinding	0.10	3	11	333	0.30	Fans
8-3-95	2107	Area	SS line	0.11	3	370	1110	0.10	-
8-3-95	2089	B	SS line-GTAW	0.10	3	378	1134	0.09	No
8-3-95	2106	F	Boilerplate	3.53	3	121	363	9.72	Yes
8-3-95	2121	F	Boilerplate	2.63	3	152	456	5.77	Yes
8-3-95	2119	F	Boilerplate	1.79	3	103	309	5.79	Yes
8-3-95	2094	Area	Trailer	0	3	391	1173	0	-
8-3-95	2116	E	Boilerplate	1.70	3	104	312	5.45	Yes?
8-3-95	2118	D	SS line-GMAW	0.47	3	92	276	1.70	No
8-3-95	2108	Area	Outside	0.02	3	413	1239	0.02	-
8-3-95	2127	E	Boilerplate	2.38	3	146	438	5.43	Yes?
8-3-95	2100	Area	SS line	0.10	3	370	1110	0.09	-
8-3-95	2124	H	Boilerplate	0.43	3	104	312	1.38	Yes
8-3-95	2115	D	SS line-GMAW	0.54	3	184	552	0.98	No
8-3-95	2120	H	Boilerplate	0.12	3	30	90	1.33	Yes
8-3-95	2093	C	SS line-GTAW	0.24	3	375	1125	0.21	No
8-3-95	2109	D	SS line-GTAW	0.04	3	65	195	0.21	No
8-3-95	2088	A	SS station-GMAW	1.72	3	258	774	2.22	No
8-3-95	2104	E	Boilerplate	3.47	3	128	384	9.04	Yes?

APPENDIX F: ELEMENTAL AIR SAMPLING DATA

Sample #	Welder or Area	Vol (m^3)	Al $\mu g/m^3$	As $\mu g/m^3$	Ba $\mu g/m^3$	Be $\mu g/m^3$	Ca $\mu g/m^3$	Cd $\mu g/m^3$	Co $\mu g/m^3$	Cr $\mu g/m^3$	Cu $\mu g/m^3$	Fe $\mu g/m^3$	Li $\mu g/m^3$	Mg $\mu g/m^3$	Mn $\mu g/m^3$	Mo $\mu g/m^3$
2203	A	861	4.3	ND	0.2	ND	34.8	ND	0.2	105.7	7.1	336.8	ND	2.3	83.6	1.2
2110	Outside	492	ND	ND	0.1	0.0	ND	ND	ND	ND	ND	1.2	ND	ND	0.5	ND
2335	C	1.215	0.8	ND	0.1	ND	3.7	ND	ND	2.6	0.2	11.5	ND	0.8	3.0	ND
2330	SS line	1.134	0.7	ND	0.2	0.0	2.6	ND	ND	1.8	0.2	10.6	0.1	0.9	3.1	ND
2091	F	06	15	ND	1.0	ND	50	ND	ND	10	6.7	866.7	ND	13.3	266.7	ND
2347	B	1.206	0.7	ND	0.0	ND	2.5	0.1	ND	3.1	0.4	10.8	ND	0.7	8.3	ND
2096	E	213	9.9	ND	1.3	ND	18.8	ND	ND	56.3	6.6	1596.2	ND	4.7	356.8	ND
2090	A	258	3.9	ND	0.4	ND	19.0	ND	ND	81.4	5.8	248.1	ND	3.5	81.4	1.2
2348	D	771	2.6	ND	0.3	ND	9.5	ND	ND	29.8	3.6	114.1	ND	1.3	31.1	0.4
2098	F	495	4.0	ND	0.8	ND	10.9	0.4	ND	4.0	4.2	909.1	ND	4.8	464.6	ND
2095	F	297	3.0	ND	2.9	ND	20.5	ND	ND	1.7	5.7	94.3	ND	ND	3.7	ND
2341	E	435	2.3	ND	0.6	ND	6.9	0.2	ND	16.1	2.3	436.8	ND	2.1	57.5	ND
2102	D	0.261	7.7	ND	0.2	ND	11.5	0.3	ND	214.6	14.9	728	ND	15.3	180.1	3.4
2092	Boiler	1.17	3.0	ND	0.1	ND	10.3	ND	ND	6.8	1.8	153.8	ND	1.7	22.2	ND
2111	Trailer	0.954	0.7	ND	ND	0.0	4.2	ND	ND	0.6	ND	3.1	0.1	ND	0.8	ND
2097	E	0.351	12.8	ND	2.8	ND	28.5	ND	ND	59.8	8.8	1794.9	0.2	8.0	398.9	ND
2336	F	0.345	10.7	ND	1.7	ND	27.8	ND	ND	17.1	16.2	2058	ND	15.4	1246.4	ND
2199	Boiler	0.738	8.8	ND	0.3	ND	39.3	0.1	ND	3.3	29.8	203.3	ND	6.4	13.4	ND
2185	C	0.186	5.4	ND	0.3	ND	36.6	ND	ND	3.2	0.5	15.6	ND	4.8	1.8	ND
2346	D	0.279	3.6	ND	0.3	ND	14.3	ND	ND	100.4	9.0	347.7	ND	3.6	93.2	1.4
2186	E	0.216	19.9	ND	3.3	ND	32.4	0.5	1.4	13.0	40.3	14351.9	ND	55.6	7407.4	ND
2191	E	0.285	11.9	ND	1.2	ND	28.4	0.4	ND	17.2	13.3	4210.5	ND	17.5	2070.2	ND

APPENDIX F: ELEMENTAL AIR SAMPLING DATA (Continued)

Sample #	Welder or Area	Vol (m³)	Al µg/m³	As µg/m³	Ba µg/m³	Be µg/m³	Ca µg/m³	Cd µg/m³	Co µg/m³	Cr µg/m³	Cu µg/m³	Fe µg/m³	Li µg/m³	Mg µg/m³	Mn µg/m³	Mo µg/m³
2189	F	0.228	37.7	ND	3.6	ND	57.0	0.4	ND	12.3	17.1	4824.6	ND	23.2	2894.7	ND
2202	A	0.36	8.6	ND	0.2	ND	20.8	ND	ND	152.8	8.6	416.7	ND	5.6	133.3	1.1
2184	Grinding	3.582	3.9	ND	0.1	ND	8.9	ND	ND	4.7	0.2	23.2	ND	1.4	1.5	ND
2182	F	0.303	6.9	ND	0.5	ND	25.7	ND	ND	5.3	11.2	429.0	ND	3.3	138.6	ND
2204	C	0.312	5.4	ND	0.1	0.1	16.3	ND	ND	2.6	0.3	11.5	ND	3.2	1.9	ND
2192	Trailer	0.801	ND	ND	ND	ND	ND	ND	ND	0.7	0.2	3.7	ND	ND	0.9	ND
2198	B	0.18	4.4	ND	0.2	ND	22.2	0.4	ND	2.2	ND	11.1	ND	4.4	1.4	ND
2205	SS line	0.633	3.3	ND	0.3	ND	15.8	0.1	ND	1.4	0.2	8.2	0.1	3.2	1.4	ND
2195	A	0.123	5.7	ND	ND	ND	16.3	ND	ND	48.8	3.3	162.6	ND	ND	50.4	ND
2193	G	0.267	7.1	ND	1.5	ND	23.2	ND	ND	10.9	9.4	2134.8	ND	10.1	1011.2	ND
2183	Outside	0.393	ND	ND	0.5	0.1	10.2	ND	ND	ND	ND	5.3	ND	2.5	1.9	ND
2200	B	0.306	3.3	ND	0.2	0.1	13.7	ND	ND	4.6	0.3	15.7	ND	2.6	5.6	ND
2187	H	0.243	4.1	ND	0.7	ND	12.3	ND	ND	7.0	3.0	82.3	ND	ND	353.9	ND
2188	G	0.294	10.2	ND	1.1	ND	40.8	ND	ND	8.5	14.3	1632.7	ND	10.5	612.2	ND
2099	Boiler	1.275	3.1	ND	0.1	ND	11.0	ND	ND	2.5	1.6	196.1	ND	2.0	14.9	ND
2114	Grinding	1.101	6.4	ND	0.1	ND	7.5	ND	ND	8.4	1.0	80.8	ND	0.9	6.4	ND
2087	I	0.78	10.8	ND	0.1	0.0	8.6	ND	ND	7.6	0.5	34.6	ND	ND	5.0	ND
2117	A	0.288	3.5	ND	0.1	ND	10.4	ND	ND	191.0	13.9	590.3	0.2	3.5	187.5	1.9
2125	I	0.333	3.0	ND	0.2	ND	16.2	ND	ND	8.1	0.6	54.1	0.2	ND	4.8	ND
2107	SS line	1.11	0.9	ND	0.1	ND	5.9	ND	ND	3.2	0.3	13.5	ND	0.9	3.6	ND
2089	B	1.134	0.9	ND	0.1	ND	6.1	ND	ND	2.1	0.3	10.6	ND	0.9	2.7	ND

APPENDIX F: ELEMENTAL AIR SAMPLING DATA (Continued)

Sample #	Welder or Area	Vol (m³)	Al µg/m³	As µg/m³	Ba µg/m³	Be µg/m³	Ca µg/m³	Cd µg/m³	Co µg/m³	Cr µg/m³	Cu µg/m³	Fe µg/m³	Li µg/m³	Mg µg/m³	Mn µg/m³	Mo µg/m³
2106	F	0.363	11.0	ND	1.3	ND	35.8	0.6	ND	6.1	14.3	2176.3	ND	14.6	1267.2	ND
2121	F	0.456	2.2	ND	0.7	ND	9.6	0.4	ND	7.9	5.0	1271.9	ND	5.5	811.4	ND
2119	F	0.309	19.4	ND	0.9	ND	55.0	0.3	ND	8.7	7.4	1294.5	ND	9.4	809.1	ND
2094	Trailer	1.173	ND	ND	ND	0.0	ND	ND	ND	0.4	0.1	3.9	ND	ND	0.5	ND
2116	E	0.312	83.3	ND	2.4	ND	147.4	ND	ND	22.8	7.7	1762.8	ND	32.1	544.9	ND
2118	D	0.276	2.5	ND	0.1	ND	10.9	ND	ND	112.3	8.0	398.6	ND	3.6	94.2	1.8
2108	Outside	1.239	ND	ND	ND	ND	1.6	ND	ND	ND	ND	3.7	ND	0.6	0.2	ND
2127	E	0.438	10.3	ND	2.3	ND	25.1	ND	ND	22.8	6.6	1735.2	ND	6.2	502.3	0.0
2100	SS line	1.11	0.9	ND	0.0	ND	4.8	ND	ND	2.2	0.2	9.9	ND	0.8	2.4	ND
2124	H	0.312	3.2	ND	0.4	0.1	17.0	ND	ND	7.1	3.1	416.7	ND	ND	70.5	ND
2115	D	0.552	1.8	ND	0.1	ND	8.9	ND	ND	56.2	4.5	199.3	ND	1.8	47.1	0.9
2120	H	0.09	ND	ND	1.7	0.2	33.3	ND	ND	5.6	3.7	388.9	ND	ND	77.8	ND
2093	C	1.125	1.5	ND	0.1	0.0	6.1	ND	ND	3.8	0.4	32.9	ND	1.8	4.6	ND
2109	D	0.195	ND	ND	ND	ND	ND	ND	ND	2.6	0.5	16.9	0.3	3.6	3.8	ND
2088	A	0.774	3.6	ND	0.2	ND	9.9	0.1	0.4	180.9	11.8	542.6	ND	2.6	193.8	1.7
2104	E	0.384	9.9	ND	2.2	ND	17.4	0.2	ND	33.9	8.9	2604.2	ND	7.8	1015.6	0.0

APPENDIX F: ELEMENTAL AIR SAMPLING DATA (Continued)

Sample #	Welder or Area	Vol (m^3)	Ni $\mu g/m^3$	Pb $\mu g/m^3$	P_4 $\mu g/m^3$	Pt $\mu g/m^3$	Se $\mu g/m^3$	Ag $\mu g/m^3$	Na $\mu g/m^3$	Te $\mu g/m^3$	Th $\mu g/m^3$	Ti $\mu g/m^3$	V_2O_5 $\mu g/m^3$	Y $\mu g/m^3$	Zn $\mu g/m^3$	Zr $\mu g/m^3$
2203	A	.861	49.9	ND	ND	ND	ND	0.1	11.6	ND	ND	0.5	0.2	ND	6.7	ND
2110	Outside	.492	ND	ND	ND	ND	ND	0.1	ND	ND	ND	ND	ND	ND	0.2	ND
2335	C	1.215	1.2	ND	ND	ND	ND	0.1	ND	ND	ND	ND	ND	ND	0.2	ND
2330	SS line	1.134	0.9	ND	ND	ND	ND	0.1	ND	ND	ND	ND	ND	0	0.3	ND
2091	F	.06	ND	ND	ND	ND	ND	1.7	150	ND	ND	36.7	ND	ND	3.3	ND
2347	B	1.206	1.2	ND	ND	ND	ND	0.1	ND	ND	ND	0	ND	ND	0.2	ND
2096	E	.213	31.0	ND	ND	ND	ND	0.3	183.1	ND	ND	117.4	1.4	ND	3.8	ND
2090	A	.258	35.3	ND	ND	ND	ND	0.2	ND	ND	ND	1.3	ND	ND	1.5	ND
2348	D	.771	15.6	ND	ND	ND	ND	ND	ND	ND	ND	0.6	ND	ND	0.4	ND
2098	F	.495	4.4	1.8	ND	ND	ND	0.2	242.4	ND	ND	34.3	0.6	ND	3.6	ND
2095	F	.297	ND	ND	ND	ND	ND	0.2	ND	ND	ND	2.0	ND	ND	4.7	ND
2341	E	.435	11.0	ND	ND	ND	ND	0.2	23.0	ND	ND	36.8	ND	ND	2.0	ND
2102	D	0.261	114.9	2.7	19.2	ND	ND	0.3	ND	3.4	ND	2.3	ND	ND	1.6	ND
2092	Boiler	1.17	2.1	ND	ND	ND	ND	0	12.8	ND	ND	6.2	ND	ND	0.5	ND
2111	Trailer	0.954	ND	ND	ND	ND	ND	0.1	ND	ND	ND	ND	ND	ND	0.6	ND
2097	E	0.351	34.2	ND	ND	ND	ND	0.1	216.5	ND	ND	169.7	0.9	ND	9.1	1.0
2336	F	0.345	12.2	4.6	ND	ND	ND	0.4	782.6	ND	ND	104.3	1.4	0.1	9.0	0.9
2199	Boiler	0.738	1.8	ND	ND	ND	ND	0.1	8.1	ND	ND	6.8	ND	ND	1.4	ND
2185	C	0.186	ND	ND	ND	ND	ND	0.3	ND	ND	ND	0.5	ND	ND	9.7	ND
2346	D	0.279	57.3	ND	ND	ND	ND	ND	ND	ND	ND	0.7	ND	ND	0.7	ND
2186	E	0.216	60.2	24.5	27.8	ND	ND	1.3	4166.7	ND	13.9	449.1	6.5	ND	55.6	3.3

APPENDIX F: ELEMENTAL AIR SAMPLING DATA (Continued)

Sample #	Welder or Area	Vol (m^3)	Ni $\mu g/m^3$	Pb $\mu g/m^3$	P_4 $\mu g/m^3$	Pt $\mu g/m^3$	Se $\mu g/m^3$	Ag $\mu g/m^3$	Na $\mu g/m^3$	Te $\mu g/m^3$	Th $\mu g/m^3$	Ti $\mu g/m^3$	V_2O_5 $\mu g/m^3$	Y $\mu g/m^3$	Zn $\mu g/m^3$	Zr $\mu g/m^3$
2191	E	0.285	23.2	6.3	ND	ND	ND	0.8	1193	ND	ND	154.4	2.2	0.1	16.5	1.1
2189	F	0.228	20.6	8.8	ND	ND	ND	0.6	1666.7	ND	ND	175.4	2.9	ND	26.8	1.3
2202	A	0.36	58.3	ND	ND	ND	ND	0.2	ND	ND	ND	1.0	ND	ND	2.3	ND
2184	Grinding	3.582	2.3	ND	ND	ND	ND	0.0	1.7	ND	ND	0.1	ND	0.0	0.2	ND
2182	F	0.303	4.6	ND	ND	ND	ND	0.3	69.3	ND	ND	23.1	ND	0.1	2.0	ND
2204	C	0.312	ND	ND	ND	ND	ND	0.2	ND	ND	ND	ND	ND	ND	0.6	ND
2192	Trailer	0.801	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND
2198	B	0.18	ND	ND	ND	ND	ND	0.6	ND	ND	ND	ND	ND	ND	1.1	ND
2205	SS line	0.633	0.6	ND	ND	ND	ND	0.1	15.8	ND	ND	0.4	ND	ND	0.6	ND
2195	A	0.123	22.8	ND	ND	ND	ND	0.6	ND	6.5	ND	ND	ND	ND	0.7	ND
2193	G	0.267	12.0	3.4	ND	ND	ND	0.4	636.7	ND	ND	82.4	1.1	ND	12.0	ND
2183	Outside	0.393	ND	ND	ND	ND	ND	0.1	ND	ND	ND	0.2	ND	ND	0.9	ND
2200	B	0.306	2.3	ND	ND	ND	ND	0.1	ND	ND	ND	0.3	ND	ND	0.3	ND
2187	H	0.245	5.8	ND	ND	ND	ND	0.2	214.0	ND	ND	32.1	ND	ND	5.3	ND
2188	G	0.294	9.2	3.1	ND	ND	ND	0.2	408.2	ND	ND	57.8	ND	ND	7.8	ND
2099	Boiler	1.275	1.7	ND	ND	ND	ND	0.0	7.8	ND	ND	6.8	ND	0.0	0.3	ND
2114	Grinding	1.101	3.8	ND	ND	ND	ND	0.1	ND	ND	ND	0.3	ND	ND	0.4	ND
2087	I	0.78	3.3	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND	ND	0.4	ND
2117	A	0.288	90.3	ND	ND	ND	ND	0.2	ND	ND	ND	0.3	ND	0.1	1.4	ND
2125	I	0.333	3.9	ND	ND	ND	ND	0.2	ND	2.1	ND	ND	ND	ND	0.8	ND
2107	SS line	1.11	1.2	ND	ND	ND	ND	0.1	ND	ND	ND	0.1	ND	ND	0.3	ND

APPENDIX F: ELEMENTAL AIR SAMPLING DATA (Continued)

Sample #	Welder or Area	Vol (m^3)	Ni $\mu g/m^3$	Pb $\mu g/m^3$	P_4 $\mu g/m^3$	Pt $\mu g/m^3$	Se $\mu g/m^3$	Ag $\mu g/m^3$	Na $\mu g/m^3$	Te $\mu g/m^3$	Th $\mu g/m^3$	Ti $\mu g/m^3$	V_2O_5 $\mu g/m^3$	Y $\mu g/m^3$	Zn $\mu g/m^3$	Zr $\mu g/m^3$
2089	B	1.134	0.8	ND	ND	ND	ND	0.1	ND	ND	ND	0.1	ND	ND	0.3	ND
2106	F	0.363	8.8	7.2	ND	ND	ND	ND	771.3	ND	ND	71.6	1.3	ND	12.7	0.6
2121	F	0.456	7.7	2.2	ND	ND	ND	0.2	438.6	ND	ND	54.8	0.7	ND	6.1	0.4
2119	F	0.309	7.1	2.3	ND	ND	ND	0.3	453.1	ND	ND	58.3	ND	ND	7.8	ND
2094	Trailer	1.173	ND	ND	ND	ND	ND	0.0	ND	0.9	ND	ND	ND	ND	ND	ND
2116	E	0.312	17.6	3.2	ND	ND	ND	0.2	352.6	ND	ND	109.0	ND	ND	7.7	1.0
2118	D	0.276	68.8	ND	ND	ND	ND	0.2	ND	ND	ND	1.3	ND	ND	0.4	ND
2108	Outside	1.239	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND
2127	E	0.438	17.4	2.3	ND	ND	ND	0.2	319.6	ND	ND	107.3	0.7	0.0	7.1	1.0
2100	SS line	1.11	0.9	ND	ND	ND	ND	0.0	ND	ND	ND	0.2	ND	ND	0.2	ND
2124	H	0.312	3.2	ND	ND	ND	ND	0.1	32.1	ND	ND	25.0	ND	ND	1.0	ND
2115	D	0.552	30.8	ND	ND	ND	ND	ND	ND	ND	ND	0.6	ND	ND	0.5	ND
2120	H	0.09	ND	ND	ND	ND	ND	0.4	ND	ND	ND	8.6	ND	ND	4.3	ND
2093	C	1.125	2.0	ND	ND	ND	ND	0.1	ND	ND	ND	0.2	ND	ND	0.4	ND
2109	D	0.195	ND	ND	ND	ND	ND	0.4	ND	ND	ND	1.9	ND	ND	1.0	ND
2088	A	0.774	74.9	ND	ND	ND	ND	0.1	ND	ND	ND	0.8	0.4	ND	0.8	ND
2104	E	0.384	23.2	5.7	ND	ND	ND	0.4	651.0	ND	ND	169.3	0.8	0.1	11.2	1.4

APPENDIX G: MEAN ELEMENTAL SAMPLE CONCENTRATIONS

ELEMENT	PERSONAL Mean (Std Dev) (µg/m3)	AREA Mean (Std Dev) ($\mu g/m^3$)
Aluminum	8 6 (13 2)	2 1 (2 6)
Arsenic	0 (0)	0 (0)
Barium	0 9 (1)	0 1 (0 1)
Beryllium	0 (0)	0 (0)
Calcium	23 2 (23 2)	8 1 (9 5)
Cadmium	0 1 (0 2)	0 (0)
Cobalt	0 (0 2)	0 (0)
Chromium	38 (55)	2 4 (2 5)
Copper	7 1 (7 1)	2 4 (7 4)
Iron	1180 (2280)	47 9 (71 5)
Lithium	0 (0 1)	0 (0)
Magnesium	7 (10)	1 4 (1 6)
Manganese	536 (1200)	4 9 (6 4)
Molybdenum	0 3 (0 7)	0 (0)
Nickel	21 5 (27)	1 (1 1)
Lead	1 8 (4 1)	0 (0)
Phosphorus	1 1 (5)	0 (0)
Platinum	0 (0)	0 (0)
Selenium	0 (0)	0 (0)
Silver	0.3 (0 3)	0 1 (0)
Sodium	295 (687)	3 1 (5 2)
Tellurium	0.3 (1 1)	0 1 (0 2)
Thallium	0 3 (2 1)	0 (0)
Titanium	46 4 (79 8)	1 4 (2 6)
Vanadium	0 5 (1 1)	0 (0)
Yttrium	0 (0)	0 (0)
Zinc	5 7 (9 3)	0 4 (0 3)
Zirconium	0 3 (0 6)	0 (0)