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FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
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MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
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N1-98-2

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Shipyard Welding Emission Factor Development

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
National Steel and Shipbuilding Company
San Diego, California

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Final Report

Shipyard Welding Emission Factor Development
Project No. N1-98-2

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NATIONAL SHIPBUILDING RESEARCH PROGRAM

FACILITIES AND ENVIRONMENTAL EFFECTS PANEL

SP-1

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Abstract/Overview

The shipbuilding and repair industry in the United States uses a large variety of rods and wires when joining metal pieces by welding. Additionally, various types of welding processes are also employed depending upon the type(s) of metals being joined and the required performance standard of the weld. Depending upon the types of rod and wire used and the welding process employed, different types and quantities of air emissions will be generated. Some types of emissions that are generated from welding have been recognized as having potential human health effects. The type and severity of these health effects will vary depending upon the duration and concentration of the exposure of any particular hazardous substance. Therefore, in order to more accurately estimate any potential health effect derived from welding emissions, it is important to accurately quantify the emission rate (grams of emission per second of process, when expressed as a function of time; or grams of emissions per lbs of welding rod/wire, when expressed as a function of mass).

Atlantic Marine, Inc. (AMI), in association with LFR Levine Fricke (LFR), and Dana M. Austin Environmental Consulting (AECI) conducted a series of tests to develop emission factors for shipyard welding operations. Tests were conducted in a controlled environment where steel components will be welded to simulate typical shipyard welding conditions.

Testing took place in a test enclosure that captured and exhausted all emissions from the welding process. The enclosure exhausted through a duct where emission measurements were conducted. USEPA test methods were utilized to measure total suspended particulate (TSP) particulate matter less than 10 and 2.5 microns (PM10 and PM2.5) and various metals. Based on the results of the shipyard survey conducted by AECI (see Task 1 Report), tests conducted for two different welding methods using eight different rods/wire. Emission factor development testing was completed at the Atlantic Marine Inc. (AMI) Mayport facility in Jacksonville, Florida from October 4 through 13, 1999.

Fume samples were analyzed in accordance with the USEPA Reference Methods specified in Task 4: Report on Collection of Fume Samples. Using the analytical data, source sampling data and measured exhaust duct flow rates, mass emission rates were calculated for each test. These data, along with the rod/wire use amounts were used to calculate emission factors for each test. The emission factors are presented on a mass emission rate per mass of rod consumed basis.

Task One: Selection of Welding Process and Type Rod/Wire

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Task One: Selection of Welding Process and Type Rod/Wire

Introduction

Previous studies by the NSRP[1] has determined that the emission factors for the various hazardous air pollutants generated during welding were dependent on two factors:

The shipbuilding and repair industry in the United States uses large varieties of rods and wires when joining metal pieces by welding. Additionally, various types of welding processes are also employed depending upon the type(s) of metals being joined and the required performance standard of the weld. Depending upon the types of rod and wire used and the welding process employed, different types and quantities of air emissions will be generated. Some types of emissions that are generated from welding have been recognized as having potential human health effects. The type and severity of these health effects will vary depending upon the duration and concentration of the exposure of any particular hazardous substance. Therefore in order to more accurately estimate any potential health effect derived from welding emissions, it is important to accurately quantify the emission rate (grams of emission per second of process, when expressed as a function of time; or grams of emissions per lbs of welding rod/wire, when expressed as a function of mass).

1. Type of rod/wire employed; and,
2. Type of welding process conducted.

As many combinations of types of rod/wires and welding processes could potentially be used in the shipyard, it was necessary to determine which types of rod/wires and processes were the most common. Additionally, we also required information on the relative volume of usage of the various rod/wires and their compositions in order to determine which rod/wires might have the greatest health impact so as to quantify their emissions rates.

This was done by conducting a survey of the shipbuilding and repair industry to determine which rod/wires were used in conduction with which types of welding processes on a scale of relative mass of the rod/wire. In this manner, it was hoped to determine a “short list” of rods/wires and welding processes to undergo actual testing later in this project.

Welding Process and Rod/Wire Survey

A survey form was devised which allowed shipyards to indicate the relative mass of rod/wire used annually, associated with a given welding process (see Appendix 1: Welding Process and Rod/Wire Selection Survey). The survey form was designed to obtain the required information for this project while imposing a minimum burden on the responding shipyard. Two hundred and twenty three (223) surveys were faxed to shipyards in the major shipbuilding and repair regions[2] of the United States. Responses were received back from twenty shipyards, resulting in

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[1] NSRP Task N1-92-1, Subtask 1: *Characterizing Shipyard Welding Emissions and Associated Control Options*; prepared by Jacobs Environmental Engineering Services, August 1995.

[2] New England States, Mid-Atlantic States, Southeastern States, Gulf Coast States, California and Pacific Northwest States.

a response rate of approximately 10%. The results of the survey are provided in the Appendix 2: Welding Process and Rod/Wire Selection Matrix.

After the compilation of the survey results we obtained the material composition data for all rods/wires with any indicated usage in the shipbuilding and repair industry from the manufacturer supplied material safety data sheet. This information resulted in a determination as to which rod/wires contained specific hazardous air pollutants ("HAP") along with their percent composition in the rod/wire. Three specific HAPs of concern were identified:

1. Chrome and chromium compounds;
2. Nickel and nickel compounds; and
3. Manganese and manganese compounds.

Using the assumption that these specific rod/wires with the highest concentration of the HAPs were likely to have the greatest potential health impact, the matrix was first sorted by percent concentration of HAPs. This data was then further sorted by relative usage mass. In this manner, those rod/wires with the greatest potential health impact and the greatest usage in the shipyard were determined.

Examination of the ***Welding Process and Rod/Wire Selection Matrix*** allows us to draw three generalities regarding HAP content, rod/wire usage and welding processes. These are:

1. Those rod/wires reported to be used in the largest amounts (> 10,000 pounds annually) did not contain chromium or nickel, but did contain manganese and manganese compounds in concentrations ranging from 0.5 to 5.0 percent.
2. Most rod/wires reported to be used in amounts ranging from less than 1,000 to greater than 10,000 pounds annually contained chromium and chromium compounds in concentrations ranging from 25 to 36 percent; contained nickel and nickel compounds ranging in concentration from 13 to 22 percent; and, manganese and magnesium compounds ranging in concentration from 2 to 7 percent.
3. Shielded Metal Arc Welding (SMAW) and Submerged Arc Welding (SAW) were the welding processes used with most high HAP concentration and moderate mass (>1,000 and < 10,000 pounds annually) usage rods.

Eight rod/wires were determined to be high enough in HAP content and usage to warrant further consideration for emission factor testing. These are shown in Table One below:

Table One: Rod/Wires Selected for Emission Factor Testing

AWS Classification Number	Welding Process	MSDS Number	Chromium & Chromium Compounds (Percent)	Nickel & Nickel Compounds (Percent)	Manganese & Manganese Compounds (Percent)
E308-16, E308L-16	Stick (SMAW)	US-M400-C	36.00	22.00	7.00
E309-16	Stick (SMAW)	US-M400-C	36.00	22.00	7.00
E308-17, E308L-17	Stick (SMAW)	US-M460-C	35.00	13.00	3.00

E309-17, E309L-17	Stick (SMAW)	US-M460-C	35.00	13.00	3.00
E316-16, E316L-16	Stick (SMAW)	US-M435-C	31.00	22.00	7.00
E308-16, E308H-16	Stick (SMAW)	US-M435-C	31.00	22.00	7.00
ER309, ER309L	Submerged Arc (SAW)	US-W325-C	25.00	13.00	2.00
ER316, ER316L	Submerged Arc (SAW)	US-W325-C	25.00	13.00	2.00

These rod/wires are the most likely to make up the majority of HAP emissions from welding in the shipyard. While it was determined that other types of welding rods were used in much greater volumes, their low, or no HAP content reduces the significance of their emissions in this project.

Conclusions

A survey of relative rod/wire and welding process was conducted and the results analyzed. The material compositions of the rod/wires were identified, and the concentrations of HAP substances were determined. Of the many types of rod/wires used in shipyard, eight were deemed to have the greatest potential for off-site health impacts from the emissions of HAPs. Task Two in this study will establish an appropriate emission factor testing protocol for these selected rod/wires, their welding processes and HAP emissions.

Appendix One: Welding Process and Rod/Wire Survey

<u>This letter is to request information regarding the types of welding processes and welding rod used at your shipyard.</u> The information will be used to develop standardized emission factors in the U.S. shipbuilding and repair industry for determination of particulate matter emissions of Hazardous Air Pollutants (HAPs) and Toxic Air Contaminants (TACs) from production welding operations at shipyards. This welding emissions research project is being conducted under contract to the National Shipbuilding Research Program (NSRP).

<u>The person most knowledgeable about welding operations in your facility can complete the following survey, which is being sent to over 200 shipyards in the U.S., in less than 10 minutes.</u> Any information your facility provides will be kept confidential and only the results of the complied data received from all shipyards will be reported in the final NSRP report. Please forward this request and the attached "fax-back" survey form to the appropriate personnel at your facility who has knowledge regarding the type(s) of production welding operations and amounts of welding rod used at your facility. When the survey form is completed, please fax it back to Austin Environmental, Inc. (AEI), the company that is compiling the data regarding welding operations and welding rod usage for this project.

<u>You received this survey because your company is listed in the most recent listing of shipyards operating in the United States.</u> If this information is incorrect and your facility <u>is not a shipyard</u>, please write "NOT SHIPYARD" on the survey form and fax it back. Your company will be removed from the shipyard database to prevent it from receiving information requests, like this, in the future.

<u>Thank you for your assistance in this important research project.</u> If you would like additional information regarding this survey or this project, please contact Mr. Tim L. Sturdavant, Austin Environmental, Inc., at telephone number (501) 455-5294 in Little Rock, Arkansas. Please complete the attached survey and fax back to "Tim L. Sturdavant – Fax Number (501) 455-2343"

AWS Rod Classifications	Check The Boxes That Apply				Welding Process
		Rod Usage (lbs. / Year)			
	Type of Welding Rod Used	< 1,000	Between 1,000 to 10,000	> 10,000	
MILD STEEL FLUX-CORED WIRES					**Gas Shielded**
E70T-1 and E70T-9					**GMAW**
E70T-1, E70T-9, E70T-1H8, E70T-9H8					**TIG**
E70T-1H4, E70T-9H4					**PAW**
E71T-1 and E71T-9					
LOW ALLOY FLUX-CORED WIRES					
E70T-5JH4					
E70T-5, E70T-5MJH4					
E81T1-B2					
E80T1-K2					
E81T1-Ni1					
E91T1-K2					
MILD STEEL METAL-CORED WIRES					
E70C-6C					
E70C-6M					
E70C-6MH4					
LOW ALLOY METAL-CORED WIRES					
E90C-G					
E110C-G					
E120C-G					
E308LT0-1 and E308LTO-4					
E309LT0-1 and E309LTO-4					
E316LT0-1 and E316LTO-4					
EC409					
EC409					
FAST-FREEZE GROUP - SPECIFIC APPLICATIONS					**Stick - SMAW**
E6010					
E6022					
E6011					
FAST FREEZE GROUP - FOR HIGH TENSILE PIPE WELDING					
E8010-G					
E7010-A1					
E7010-G					
FAST-FILL GROUP					
E7024-1					
E6027					
E7024					
FILL-FREEZE GROUP					
E6012					
E6013					
E7014					
LOW HYDROGEN GROUP					
E7018H4R					
E7018-1 H4R					
E7018H8					
E7028H8					
LOW HYDROGEN, LOW ALLOY GROUP					
E8018-B2H4R					
E9018-B3H4R					
E8018-C3H4R					

AWS Rod Classifications	Check The Boxes That Apply				Welding Process
		Rod Usage (lbs. / Year)			
	Type of Welding Rod Used	< 1,000	Between 1,000 to 10,000	> 10,000	
E8018-C1H4R					
MIL-10018-M1					Stick - SMAW
E11018-MH4R					
E308-17, E308L-17					
E309-17, E309L-17					
E316-17, E316L-17					
N/A					
E308-16, E308L-16					
E309-16					
E310-16					
E316-16, E316L-16					
E308L-16					
E308-15, E308L-15					
E308-16, E308H-16					
E309-16, E309L-16					
E309-15, E309L-15					
E310-16					
E316-16, E316L-16					
E316-15, E316L-15					
E347-16					
CAST IRON AND ALUMINUM					
ENiFe-CI					
ENi-CI					
ESt					
E4043					
CORED WIRE					Submerged Arc - SAW
ECB2					
EMC2					
ECNi2					
EC1					
ECG					
SOLID WIRE					
EA1					
EH11K, ER70S-6					
EM14K					
EG					
EF2					
ER80S-D2, ER90S-D2, EA3K					
EB2					
EB3					
EH12K					
EL 12					
EM2, ER100S-G, ER110S-G					
EM12K					
ER308, ER308L					
ER309, ER309L					
ER316, ER316L					
EM13K					
MIG					MIG - GMAW
ER70S-3					
ER70S-3					
ER70S-4					

AWS Rod Classifications	Check The Boxes That Apply				Welding Process
		Rod Usage (lbs. / Year)			
	Type of Welding Rod Used	< 1,000	Between 1,000 to 10,000	> 10,000	
ER70S-6					
ER70S-6					
ER80S-Ni1					
ER80S-D2, ER90S-D2					
ER308Si/E308LSi					
ER309Si/E309LSi					
ER316Si/E316LSi					
ER100S-G,ER110S-G					
HIGH SPEED SINGLE PASS FLUX-CORED WIRES					**Self Shielded - GMAW, FCAW**
E70T-3					
E70T-3					
E70T-10					
E71T-14					
E71T-14					
GENERAL PURPOSE FLUX-CORED WIRES					
E71T-7					
E71T-11					
E71TG-G					
STRUCTURAL FABRICATION FLUX-CORED WIRES					
E71T-8J					
E71T-8J					
E71T8-Ni1					
E61T8-K6					
E71T8-K2					
E71T-8					
E70T-6					
E70T-7					
E70TG-K2					
E71T8-K6					
E71T8-Ni2					
E70T-4					
HIGH STRENGTH PIPE WELDING FLUX-CORED WIRES					
E71T-13H8					
E71T8-K6					
E91T8-G					
MECHANIZED VERTICAL UP FLUX-CORED WIRES					
EG72T-1					
EG82T-G					

AWS Rod Classifications	Check The Boxes That Apply				Welding Process
		Rod Usage (lbs. / Year)			
	Type of Welding Rod Used	< 1,000	Between 1,000 to 10,000	> 10,000	
OTHER WELDING PROCESSES AND ROD TYPE NOT NOTED ABOVE					

Appendix Two: Welding Process and Rod/Wire Selection Matrix

Welding Process and Rod/Wire Selection Matrix

AWS Rod Classification	Survey Results (number of responses)			Welding Process	MSDS Number	HAP Constituents					
	Rod Usage (Lbs/Year)					Chromium & Chromium Coupounds	% by Weight	Nickel & Nickel Compounds	% by Weight	Manganese & Manganese Compounds	% by Weight
	< 1,000	Between 1,000 to 10,000	> 10,000								
E308-16, E308L-16	1	4		Stick (SMAW)	US-M400-C	X	36.00	X	22.00	X	7.00
E309-16	1	3		Stick (SMAW)	US-M400-C	X	36.00	X	22.00	X	7.00
E308-17, E308L-17	1	2		Stick (SMAW)	US-M460-C	X	35.00	X	13.00	X	3.00
E309-17, E309L-17	1	2		Stick (SMAW)	US-M460-C	X	35.00	X	13.00	X	3.00
E316-16, E316L-16	2	2		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
E308-16, E308H-16	1	2		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
ER309, ER309L	2	2		Submerged Arc (SAW)	US-W325-C	X	25.00	X	13.00	X	2.00
ER316, ER316L	1	2		Submerged Arc (SAW)	US-W325-C	X	25.00	X	13.00	X	2.00
E6010	1	2	2	Stick (SMAW)	US-M210					X	1.00
ER100S-G,ER110S-G	1	2		MIG (GMAW)	US-W40			X	5.00	X	5.00
EH11K, ER70S-6		2		Submerged Arc (SAW)	US-W5					X	2.00
E310-16	2	1		Stick (SMAW)	US-M400-C	X	36.00	X	22.00	X	7.00
E316-17, E316L-17	1	1		Stick (SMAW)	US-M460-C	X	35.00	X	13.00	X	3.00
E316-16, E316L-16	1	1		Stick (SMAW)	US-M460-C	X	35.00	X	13.00	X	3.00
E308L-16	1	1		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
E310-16	1	1		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
E347-16	1	1		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
E308-15, E308L-15		1		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00

Welding Process and Rod/Wire Selection Matrix

AWS Rod Classification	Survey Results (number of responses)			Welding Process	MSDS Number	HAP Constituents					
	Rod Usage (Lbs/Year)					Chromium & Chromium Coupounds	% by Weight	Nickel & Nickel Compounds	% by Weight	Manganese & Manganese Compounds	% by Weight
	< 1,000	Between 1,000 to 10,000	> 10,000								
E309-16, E309L-16		1		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
E309-15, E309L-15		1		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
E316-15, E316L-15		1		Stick (SMAW)	US-M435-C	X	31.00	X	22.00	X	7.00
E309LT0-1 and E309LTO-4		1		Gas Shielded (GMAW, TIG & PAW)	US-CW800-C	X	29.00	X	15.00	X	2.00
E11018-MH4R	1	1	2	Stick (SMAW)	US-M350	X	0.50			X	5.00
E8018-C3H4R	2	1	1	Stick (SMAW)	US-M335	X	0.50			X	5.00
E71T-1 and E71T-9		1	7	Gas Shielded (GMAW, TIG & PAW)	US-CW305-C					X	5.00
E6011	1	1	5	Stick (SMAW)	US-M220					X	0.50
ER70S-3		1	3	MIG (GMAW)	US-W2					X	1.00
E7018H4R		1	2	Stick (SMAW)	US-M290					X	5.00
E70T-1 and E70T-9		1	1	Gas Shielded (GMAW, TIG & PAW)	US-CW300-C					X	5.00
E91T1-K2		1		Gas Shielded (GMAW, TIG & PAW)	US-CW340			X	5.00	X	5.00
E81T1-Ni1		1		Gas Shielded (GMAW, TIG & PAW)	US-CW335			X	1.00	X	5.00
E7024	1	1		Stick (SMAW)	US-M270					X	5.00
E7024-1	1	1		Stick (SMAW)	US-M260					X	5.00
EH12K		1		Submerged Arc (SAW)	US-W50					X	2.00

Welding Process and Rod/Wire Selection Matrix

AWS Rod Classification	Survey Results (number of responses)			Welding Process	MSDS Number	HAP Constituents					
	Rod Usage (Lbs/Year)					Chromium & Chromium Coupounds	% by Weight	Nickel & Nickel Compounds	% by Weight	Manganese & Manganese Compounds	% by Weight
	< 1,000	Between 1,000 to 10,000	> 10,000								
E4043	1			Stick (SMAW)	US-W350-C	N/A	N/A	N/A	N/A	N/A	N/A
E308LT0-1 and E308LTO-4	2			Gas Shielded (GMAW, TIG & PAW)	US-CW800-C	X	29.00	X	15.00	X	2.00
E316LT0-1 and E316LTO-4	2			Gas Shielded (GMAW, TIG & PAW)	US-CW800-C	X	29.00	X	15.00	X	2.00
ER308, ER308L	2			Submerged Arc (SAW)	US-W325-C	X	25.00	X	13.00	X	2.00
ER309Si/E309LSi	1			MIG (GMAW)	US-W70-C	X	25.00	X	13.00	X	2.00
ER316Si/E316LSi	1			MIG (GMAW)	US-W70-C	X	25.00	X	13.00	X	2.00
E8018-B2H4R	3			Stick (SMAW)	US-M338	X	5.00			X	0.50
E9018-B3H4R	3			Stick (SMAW)	US-M338	X	5.00			X	0.50
EM12K			3	Submerged Arc (SAW)	US-W15					X	1.00
E7018-1 H4R			2	Stick (SMAW)	US-M285					X	5.00
E7028H8			1	Stick (SMAW)	US-M295					X	5.00
E7018H8			1	Stick (SMAW)	US-M282					X	5.00
ER70S-4			1	MIG (GMAW)	US-W3					X	2.00
E71T-11			1	Self Shielded GMAW FCAW	US-CW140					X	0.50
ENi-CI	2			Stick (SMAW)	US-M393			X	75.00	X	1.00
ENiFe-CI	2			Stick (SMAW)	US-M394			X	60.00		
ECNi2	1			Submerged Arc (SAW)	US-CW260			X	5.00	X	5.00

Welding Process and Rod/Wire Selection Matrix

AWS Rod Classification	Survey Results (number of responses)			Welding Process	MSDS Number	HAP Constituents					
	Rod Usage (Lbs/Year)					Chromium & Chromium Coupounds	% by Weight	Nickel & Nickel Compounds	% by Weight	Manganese & Manganese Compounds	% by Weight
	< 1,000	Between 1,000 to 10,000	> 10,000								
E6013	2			Stick (SMAW)	US-M250					X	5.00
ER70S-6	3			MIG (GMAW)	US-W301-C					X	2.00
E7010-A1	1			Stick (SMAW)	US-M301					X	1.00
OTHER WELDING PROCESSES AND ROD TYPES NOT NOTED											
E308LT1-1	1			GMAW/TIG/PAW	US-CW800-C	X	29.00	X	15.00	X	2.00
ER 5356 AL	2			GTAW	US-W350-C	N/A	N/A	N/A	N/A	N/A	N/A
Carbon			1	Gouge	N/A	N/A	N/A	N/A	N/A	N/A	N/A
100S-1		2		SAW	N/A	N/A	N/A	N/A	N/A	N/A	N/A
101TC		2		FCAW	N/A	N/A	N/A	N/A	N/A	N/A	N/A
L-61		1		SAW	N/A	N/A	N/A	N/A	N/A	N/A	N/A
120S-1	2			SAW	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9N10	2			SMAW	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Welding Process and Rod/Wire Selection Matrix

AWS Rod Classification	Survey Results (number of responses)			Welding Process	MSDS Number	HAP Constituents					
	Rod Usage (Lbs/Year)					Chromium & Chromium Coupounds	% by Weight	Nickel & Nickel Compounds	% by Weight	Manganese & Manganese Compounds	% by Weight
	< 1,000	Between 1,000 to 10,000	> 10,000								
7030	2			SMAW	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T1-1	1			GTAW	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Task Two: Shipyard Welding Emission Factor Development Test Plan

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Task Two: Shipyard Welding Emission Factor Development Test Plan

Introduction

LFR Levine Fricke (LFR), along with Atlantic Marine, Inc. (AMI), and Dana M. Austin Environmental Consulting (DMAEC) will be conducting a series of tests to develop emission factors for shipyard welding operations. Tests will be conducted in a controlled environment where steel components will be welded to simulate typical shipyard welding conditions.

Testing will take place in a test enclosure that will capture and exhaust all emissions from the welding process. The enclosure will exhaust through a duct where emission measurements will be conducted. USEPA test methods will be utilized to measure total suspended particulate (TSP) particulate matter less than 10 and 2.5 microns (PM10 and PM2.5) and various metals. Based on the results of the shipyard survey conducted by DMAEC (see Task 1 Report), tests will be conducted for two different welding methods using a total of eight different rods/wire.

This test plan identifies the methodologies to be utilized to collect data that will be used to establish emission factors for particulates and hazardous air pollutants (HAPs), which is the ultimate goal of the project. This submittal covers the requirements of Task 2 in the proposal submitted by AMI.

Welding procedures

Welding will be conducted by personnel experienced in shipyard welding operations. Various steel components will be welded within the test enclosure utilizing Shielded Metal Arc Welding (SMAW) and Submerged Arc Welding (SAW) processes. These processes were chosen based on the Task 1 shipyard survey. The survey revealed that these were the predominant welding processes being conducted at shipyards utilizing rods and wires containing significant HAP components. Welding will be conducted with a total of eight different rods/wires, also as identified in the Task 1 shipyard survey. Test conditions are described in further detail in Section 4.0.

Test Facility

The test facility will be a simple wood frame structure covered with a single layer of 4-mil polyethylene sheets. The approximate dimensions of the enclosure will be approximately 15 feet by 20 feet by 10 feet tall. The overall volume will be approximately 3,000 cubic feet. This enclosure will provide sufficient space for welding equipment, steel components and an operator.

A 12-inch or greater diameter duct will be used to exhaust the enclosure. The exhaust duct will include sampling ports that meet the criteria of USEPA Reference Method 1 – Sample and Velocity Traverses for Stationary Sources. The amount of exhaust air will be approximately 1600 standard cubic feet per minute (scfm). Makeup air into the enclosure will be drawn through natural draft openings strategically placed to ensure appropriate ventilation within the enclosure and achieve effective contaminant capture. The natural draft openings will be installed to allow fresh air into the enclosure and will be designed in accordance with U.S. EPA Reference Method 204, *Criteria for and Verification of a Permanent or Temporary Total Enclosure*. A copy of Reference Method 204 is included in Appendix A. Compliance with Method 204 documents that 100 percent capture efficiency can be assumed. In addition, exhausting approximately 1600 scfm will yield a rate of over 30 air changes per hour based on the overall volume of the enclosure. This design will not only provide sufficient contaminant capture but will also maintain a safe working atmosphere for people in the enclosure. Test enclosure design and exhaust rates may be adjusted to account for field conditions. The enclosure exhaust duct will discharge to atmosphere.

Test Conditions

As indicated in the Task 1 shipyard survey report, testing will be conducted using two different welding processes in combination with a total of 8 rods/wires. Three runs at each test condition will be conducted. Table 1 summarizes the combinations of welding processes and rods/wires that will be utilized for the emission factor development test program.

Table1: Rod/Wires and Welding Processes Selected for Emission Factor Testing

Rod/Wire American Welding Society Classification Number	**Welding Process**
E308-16, E308L-16	Shielded Metal Arc Welding
E309-16	Shielded Metal Arc Welding
E308-17, E308l-17	Shielded Metal Arc Welding
E309-17, E309L-17	Shielded Metal Arc Welding
E316-16, E316L-16	Shielded Metal Arc Welding
E308-16, E308H-16	Shielded Metal Arc Welding
ER309, ER309L	Submerged Arc Welding
ER316, ER316L	Submerged Arc Welding

Test procedures

Welding will be conducted under controlled test conditions within the test enclosure. Metal parts will be welded utilizing the combination of methods and rod/wires described in Section 4.0. Each run will be a minimum of one hour in duration. The actual test time will be determined based on expected contaminant emission rates and laboratory detection limits. Three test runs will be completed for each condition.

USEPA Reference Methods will be utilized for sampling the welding fumes within the enclosure exhaust duct. The test methods and contaminants to be analyzed are summarized in Table 2.

Table 2: Parameters and Test Methods to be Utilized for Emission Factor Development

Parameter	**Test Method**
Flow Rate	USEPA Reference Method 1, *Sample and Velocity Traverses for Stationary Sources*
	USEPA Reference Method 2, *Determination of Stack Gas Velocity and Volumetric Flow Rate (Type-S Pitot Tube)*
Moisture	USEPA Reference Method 4, *Determination of Moisture Content in Stack Gas*
Total Suspended Particulate	USEPA Reference Method 5, *Determination of Particulate Emissions from Stationary Sources*
Particulate Matter less than 10 microns	USEPA Reference Method 201A, *Determination of PM10 Emissions (Constant Sampling Rate Procedure)*
	USEPA Reference Method 202, *Determination of Condensible Particulate Emissions from Stationary Sources*
Particulate Matter less than 2.5 microns	USEPA Reference Method 201A, *Determination of PM10 Emissions (Constant Sampling Rate Procedure)*
	USEPA Reference Method 202, *Determination of Condensible Particulate Emissions from Stationary Sources*
Metals – Nickel, Manganese, Lead, Cadmium and total chromium	USEPA Reference Method 29, *Determination of Metals Emissions from Stationary Sources*
Metals – Hexavalent Chromium	USEPA Reference Method 306, *Determination of Chromium Emissions from Decorative and Hard Chromium Electroplating and Anodizing Operations*

The total mass of rod/wire utilized during each test will be recorded. This information, along with the emission rate data will be used to calculate emission factors. Details on specific sampling procedures are summarized in the following sections.

Total Particulates

Summary

Particulate emissions will be determined in accordance with USEPA Reference Method 5, *Determination of Particulate Emissions from Stationary Sources*. Gaseous and particulate pollutants are withdrawn isokinetically and are collected on a glass fiber filter. The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

Preparation of Sampling Train

All sample train components coming in contact with the sample gas will be constructed of glass. All glassware will be cleansed in hot soapy water, rinsed with nitric acid, then rinsed with distilled tap water prior to use. All glassware openings will be covered until the sample train is assembled to prevent contamination.

A glass fiber filter will be loaded into a borosilicate glass filter holder with a glass or Teflon frit support.

The condenser portion of the sampling train will consist of four Greenburg-Smith impingers in series. The first two impingers will contain 100 ml of deionized distilled water. The third impinger will be empty and the fourth will contain approximately 200 to 300 grams of silica gel. All impingers will be weighed prior to sampling.

A sample control/metering system consisting of a vacuum pump, dry gas meter, sample flow controls, sample-rate manometer, stack gas velocity manometer, temperature indicator, and heat controllers will be utilized to operate the sampling train.

Leak Check Procedures

A pre-test leak check of the entire sample train will be conducted at a vacuum greater than that anticipated for the test run. A leak rate of no greater than 0.02 scfm will be achieved prior to run commencement. A post-test leak check will be performed on the entire sample train at a vacuum equal or greater than the highest vacuum achieved during the test run. If the leak rate is greater than 0.02 scfm, the run will either be voided/repeated or kept and corrected for the leak-rate.

Sample Volumes and Detection Limits

The particulate analytical detection limit is 0.0002 grams and a sample volume of at least 30 ft^3 will be collected. With an expected enclosure exhaust rate of 1600 scfm, the sampling detection limit for TSP will be approximately 0.0014 lb/hr.

Sample Train Operation

A single train traversing the exhaust duct cross sectional area shall be used for the entire test. The sampling system will consist of a sized, tapered edge nozzle constructed of stainless steel. The nozzle is connected to a stainless steel support tube via a gas-tight connection to a heated inner borosilicate glass sampling probe.

The gas stream will enter a four-inch diameter glass fiber filter supported by a quartz glass or Teflon frit. The temperature of the filter hot box will be maintained at 248ºF +/- 25ºF. The probe heat will be maintained to prevent internal moisture condensation.

The filter is connected to the impinger train consisting of four impingers immersed in an ice bath and connected in series with glass crossovers. The gases pass through all four impingers. The first two impingers, containing 100 ml of distilled water each will serve as the primary condensers. The third and fourth impingers are used as a condensate trap and drying tube respectively to ensure that no moisture reaches the dry gas meter. The fourth impinger is connected to a positive displacement pump and a calibrated dry gas meter.

Sample rate and temperature adjustments will be made at each sample point to ensure that isokinetic sampling conditions are maintained.

Sample Recovery

Sample recovery will occur onsite. The sampling system will be transferred to an area that is clean and protected from wind so that the chance of contamination and/or sample loss is minimized.

The probe nozzle glass liner, and the front half of the filter will be washed and brushed with water, then acetone, into one amber glass container until the rinse shows no visible particles (container 2). The filter is placed into a petri dish and sealed to prevent sample loss (container 1).

The impingers will be disassembled and wiped free of any water or ice, and each impinger will be weighed for exhaust gas moisture determination.

An acetone blank will be collected in an amber glass container by adding a volume of acetone that approximates the volume of the samples recovered.

Sample Shipment and Storage

All samples will be labeled and assigned chain-of-custody forms in the field. The samples will then be returned to the LFR office for refrigerated storage prior to analysis. Samples will be shipped in an iced cooler.

Analytical Procedures

The acetone rinses will be evaporated in pre-weighed containers at ambient temperature and pressure. When the evaporation is complete, the containers will be desiccated to a constant weight. The acetone blank will be subject to the same procedure.

The glass fiber filters will be transferred to a pre-weighed weighing dish and oven dried at 105 ^{o}C for two to three hours. This will be followed by cooling in a desiccator to a constant weight.

Data Reduction/Calculations

The field data and analytical results will be subject to the data reduction and calculation methodologies specified in USEPA Reference Methods 1, 2, 4, and 5. The resultant calculations will be included in emission factor development calculations.

PM10

Summary

PM10 emissions will be determined in accordance with USEPA Reference Method 201A, Determination of PM10 Emissions (Constant Sample Rate Method) and USEPA Reference Method 202, Determination of Condensible Particulate Emissions From Stationary Sources

Suspended (filterable) and condensible particulate matter with an aerodynamic particle size of 10 microns or less will be separated from the sampled gas with an in-stack cyclone and collected on a glass fiber filter and in water. Recovered samples will then be analyzed gravimetrically for particulate in accordance with Method 5 and Method 202.

Preparation of Sampling Train

The cyclone and filter holder will be cleaned with acetone prior to sampling. All glassware will be cleansed in hot soapy water and rinsed with nitric acid, then rinsed with distilled tap water prior to use. All glassware openings will be covered until the sample train is assembled to prevent contamination.

The probe will be constructed of stainless steel with a heated glass liner and will be connected to a stainless steel sample nozzle. An S-type pitot tube will be included on the probe to measure velocity as well as a thermocouple to measure stack temperature.

The condenser portion of the sampling train will consist of four Greenburg-Smith impingers in series. The first two impingers will contain 100 ml of deionized distilled water. The third impinger will be empty and the fourth will contain approximately 200 to 300 grams of silica gel. All impingers will be weighed prior to sampling.

A glass fiber filter will be loaded into the in-stack stainless steel filter holder and frit.

A sample control/metering system consisting of a vacuum pump, dry gas meter, sample flow controls, sample-rate manometer, stack gas velocity manometer, temperature indicator, and heat controllers will be utilized to operate the sampling train.

Leak Check Procedures

A pre-test leak check of the entire sample train will be conducted at a vacuum greater than that anticipated for the test run. A leak rate of no greater than 0.02 scfm will be achieved prior to run commencement. A post-test leak check will be performed on the entire sample train at a vacuum equal or greater than the highest vacuum achieved during the test run. If the leak rate is greater than 0.02 scfm, the run will either be voided/repeated or kept and corrected for the leak-rate. The pre-test leak check will include the entire sampling train while the post-test leak check will not include the in-stack cyclone.

Sample Volumes and Detection Limits

The PM10 analytical detection limit is 0.0002 grams and a sample volume of at least 30 ft^3 will be collected. With an expected enclosure exhaust rate of 1600 scfm, the sampling detection limit will be approximately 0.0014 lb/hr.

Sample Train Operation

A single train traversing the exhaust duct cross sectional area shall be used for the entire test. The sampling system will consist of an in-stack stainless steel cyclone with a sized, tapered edge nozzle also constructed of stainless steel. The cyclone will be connected to an in-stack filter holder. The filter holder is connected to a stainless steel support tube via a gas-tight connection to a heated inner borosilicate glass sampling probe.

The proper sample rate and nozzle size will be selected in accordance with Figures 4 and 5, respectively, of Method 201A. The sample time at each sample point will be varied for local delta P in accordance with Figure 6 of Method 201A. Probe heat will be maintained at a temperature that will prevent internal moisture condensation. The sample rate and nozzle size will be adjusted to maintain constant-rate sampling at each sample point.

After the heated probe, the sampled gas will pass through the condenser consisting of four impingers immersed in an ice bath and connected in series with glass crossovers. The first two impingers, containing 100 ml of distilled water each will serve as the primary condensers. The third and fourth impingers are used as a condensate trap and drying tube respectively to ensure that no moisture reaches the dry gas meter. The fourth impinger is connected to a positive displacement pump and a calibrated dry gas meter.

Sample Recovery

Sample recovery will occur onsite. The sampling system will be transferred to an area that is clean and protected from wind so that the chance of contamination and/or sample loss is minimized.

The impingers will be disassembled and wiped free of any water or ice, and each impinger will be weighed. The particulate filter and loose particulate will be transferred to a plastic petri dish (container 1). The cyclone turn-around cup, exit tube and filter holder front-half will be brushed and rinsed with acetone into an amber glass bottle (container 2). The impinger catch and a distilled water rinse of the impinger train and filter-holder back-half will be collected in an amber glass bottle (container 3). A methylene chloride rinse of the impinger train and filter-holder back-half will be conducted and collected in an amber glass bottle, (container 4).

Acetone, distilled water and methylene chloride blanks will be collected in separate amber glass containers by adding quantities that approximate the volume of the samples recovered.

Sample Shipment and Storage

All samples will be labeled and assigned chain-of-custody forms in the field. The samples will then be returned to the LFR office for refrigerated storage prior to analysis. Samples will be shipped in an iced cooler.

Analytical Procedures

PM10 analysis will be performed in accordance with USEPA Reference Method 5. Filters will be transferred to a pre-weighed dish and oven dried at 105 ^{o}C for two to three hours. This will be followed by cooling in a desiccator to a constant weight.

After measuring the quantity of acetone in container 2, its contents will be transferred to a dry, desiccated and tared Teflon beaker. After evaporating the acetone at ambient conditions, the beaker will be dried, desiccated, and re-weighed to a constant weight.

Container 3 and container 4 contents will be transferred to a separatory funnel and thoroughly mixed. The organic layer will be drained into a clean, tared glass beaker. This methylene chloride extraction will repeated twice more with 75 ml portions of methylene chloride. The organic layer from all three extractions will be collected in one beaker. After evaporating the beaker contents at ambient conditions, the beaker will be dried and desiccated to a constant weight.

The remaining separatory funnel contents will be collected in a tared beaker and analyzed in the same manner as the methylene chloride extraction.

Data Reduction/Calculations

The field data and analytical results will be subject to the data reduction and calculation methodologies specified in U.S. EPA Reference Methods 1, 2, 4, 5, 201A and 202. The resultant calculations will be included in emission factor development calculations.

Metals (excluding hexavalent chromium)

Summary

The enclosure exhaust will be sampled isokinetically for metal emissions (other than hexavalent chromium) in accordance USEPA Reference Method 29, *Determination of Metals Emissions from Stationary Sources*.

Metals in the sample gas will be collected in the sample train on a filter and in acidic impinger reagents. Recovered samples will then be digested and analyzed for total chromium (Cr), cadmium (Cd), nickel (Ni), manganese (Mn) and lead (Pb) in accordance with Method 29.

Preparation of Sampling Train

All glassware and sample containers will be cleansed in hot soapy water followed by a four-hour soak in a 10% nitric acid solution. The glassware and sample containers will then be triple rinsed with deionized distilled tap water. All glassware openings will be covered until the sample train is assembled to prevent contamination.

A low-metal quartz fiber filter will be loaded into a heated glass filter holder with a Teflon frit.

The probe will be constructed of stainless steel with a heated glass liner and will be connected to a glass "button-hook" sample nozzle. An S-type pitot tube will be included on the probe to measure velocity as well as a thermocouple to measure stack temperature.

The condenser portion of the sampling train will consist of four Greenburg-Smith impingers in series. The first impinger will be empty and will serve as a moisture trap. The second and third impingers will each contain 100 ml of a 5% nitric acid (HNO_3)/10% hydrogen peroxide (H_2O_2) solution. The fourth impinger will contain approximately 200 to 300 grams of silica gel. All impingers will be weighed prior to sampling.

A sample control/metering system consisting of a vacuum pump, dry gas meter, sample flow controls, sample-rate manometer, stack gas velocity manometer, temperature indicator, and heat controllers will be utilized to operate the sampling train.

Leak Check Procedures

A pre-test leak check of the entire sample train will be conducted at a vacuum greater than that anticipated for the test run. A leak rate of no greater than 0.02 scfm will be achieved prior to run commencement. A post-test leak check will be performed on the entire sample train at a vacuum equal or greater than the highest vacuum achieved during the test run. If the leak rate is greater than 0.02 scfm, the run will either be voided/repeated or kept and corrected for the leak-rate.

Sample Volumes and Detection Limits

Anticipated method detection limits are outlined in the following table. These values assume an expected enclosure exhaust rate of 1600 scfm and a meter volume of 44.14 DSCF. Analytical detection limits are based on using graphite furnace atomic absorption spectroscopy (GFAAS) for metals analyses.

Table 3: Estimated In-Stack Detection Limits for Metals Sampling		
Metal	**In-Stack Detection Limit**	
	μg/l	**lb/hr**
cadmium	1.5	8.99×10^{-6}
chromium	2.5	1.50×10^{-5}
lead	15.1	9.05×10^{-5}
manganese	0.7	4.20×10^{-6}
nickel	5.4	3.24×10^{-5}

Sample Train Operation

A single train traversing the exhaust duct cross sectional area shall be used for the entire test. The sampling system will consist of a sized, tapered edge “button-hook” nozzle constructed of glass. The nozzle is connected to a stainless steel support tube via a gas-tight connection to a heated inner borosilicate glass sampling probe.

The gas stream will enter a four inch diameter low-metal quartz fiber filter in a glass filter holder. The filter will be supported by a Teflon frit. The temperature of the filter hot box will be maintained at 250ºF +/- 25ºF. The probe heat will be maintained to prevent internal moisture condensation.

The filter is connected to the impinger train consisting of four impingers immersed in an ice bath and connected in series with glass crossovers. The gases pass through all four impingers. The first impinger will be empty and will serve as a moisture trap. The second and third impingers will each contain 100 ml of a 5% HNO_3/10% H_2O_2 solution and will absorb gaseous metals. The fourth impinger, containing silica gel will be connected to a positive displacement pump and a calibrated dry gas meter.

Sample rate and temperature adjustments will be made at each sample point to ensure that isokinetic sampling conditions are maintained.

Sample Recovery

Sample recovery will occur onsite. The sampling system will be transferred to an area that is clean and protected from wind so that the chance of contamination and/or sample loss is minimized.

The impingers will be disassembled and wiped free of any water or ice, and each impinger will be weighed. The particulate filter and loose particulate will be transferred to a plastic petri dish, container 1. With a non-metallic brush, the probe, nozzle and front-half of the filter holder will be rinsed and brushed three times with a total of 100 ml of 0.1N HNO3 into container 2 (high density polyethylene, HDPE). The contents of the knock-out impinger and the impingers charged with HNO_3/H2O_2 will be transferred to container 3 (HDPE). Finally, the knock-out impinger, HNO_3/H_2O_2 impingers, filter holder back-half, frit and connecting glassware will all be rinsed three times with a total of 100 ml 0.1N HNO_3 into container 3.

An unused filter will be placed in a plastic petri dish and will serve as a blank. Both front-half and back-half blanks will be collected as well. The front-half blank will include 100 ml of 0.1 N HNO_3. The back half blank will include 200 ml of the 5% HNO_3/10% H_2SO_4 solution and 100 ml of 0.1 N HNO_3. Both of these blanks will be stored in HDPE containers.

Sample Shipment and Storage

All samples will be labeled and assigned chain-of-custody forms in the field. The samples will then be returned to the LFR office for refrigerated storage prior to analysis. Samples will be shipped in an iced cooler.

Analytical Procedures

Sample preparation and analysis will be performed in accordance with EPA Reference Method 29. Prior to analysis, containers 1 and 2 will be digested in accordance with Method 29 and combined as a single analytical fraction. The contents of container 3 will also be digested prior to analysis. Samples will be analyzed for cadmium, total chromium, lead, manganese and nickel via graphite furnace atomic absorption spectroscopy.

Data Reduction/Calculations

The field data and analytical results will be subject to the data reduction and calculation methodologies specified in U.S. EPA Reference Methods 1, 2, 4, 5, and 29. The resultant calculations will be included in emission factor development calculations.

Hexavalent Chromium

Summary

Hexavalent chromium emissions will be determined in accordance with USEPA Reference Method 306. With this method, gaseous pollutants are withdrawn isokinetically and collected in an alkaline solution. The collected samples will be analyzed by an ion chromatograph equipped with a post-column reactor (IC/PCR) for hexavalent chromium.

Preparation of Sampling Train

All sample train components coming in contact with the sample gas will be constructed of glass. All glassware will be cleansed in hot soapy water and rinsed with nitric acid, then rinsed with distilled tap water prior to use. All glassware openings will be covered until the sample train is assembled to prevent contamination.

There will not be a filter on the sample train as the hexavalent chromium will be absorbed in the alkaline solution in the impingers.

The condenser portion of the sampling train will consist of four Greenburg-Smith impingers in series. The first two impingers will contain 100 ml of 0.1 N sodium hydroxide (NaOH). The third impinger will be empty and the fourth will contain approximately 200 to 300 grams of silica gel. All impingers will be weighed prior to sampling.

Leak Check Procedures

A pre-test leak check of the entire sample train will be conducted at a vacuum greater than that anticipated for the test run. A leak rate of no greater than 0.02 scfm will be achieved prior to run commencement. A post-test leak check will be performed on the entire sample train at a vacuum equal or greater than the highest vacuum achieved during the test run. If the leak rate is greater than 0.02 scfm, the run will either be voided/repeated or kept and corrected for the leak-rate.

Sample Volumes and Detection Limits

As indicated in Method 306, utilizing IC/PCR with preconcentration, the expected in-stack detection limit for hexavalent chromium is 0.000015 mg/m^3 based on a stack gas sample volume of 60 DSCF and a total liquid sample of 500 ml. At an enclosure exhaust rate of 1600 scfm, this corresponds to a detection limit of 9.0 x 10-8 lb/hr hexavalent chromium.

Sample Train Operation

A single train traversing the stacks cross sectional area shall be used for the entire test. The sampling system will consist of a sized tapered edge glass nozzle. The nozzle is connected to a stainless steel support tube via a gas-tight connection to a borosilicate glass lined sampling probe.

The probe is connected to the impinger train immersed in an ice bath and connected in-series with glass crossovers. No filter is used. The gases pass through the impingers to the dry gas meter. The hexavalent chromium is scrubbed out of the gas stream in the first two impingers containing 0.1N NaOH solution. The third and fourth impingers are used as a condensate trap and drying tube respectively to insure that no moisture reaches the dry gas meter. The fourth impinger is connected to a positive displacement pump and a calibrated dry gas meter.

Sample rate and temperature adjustments will be made at each sample point to ensure that isokinetic sampling conditions are maintained.

Sample Recovery

Sample recovery will occur onsite. The sampling system will be transferred to an area that is clean and protected from wind so that the chance of contamination and/or sample loss is minimized.

The impingers will be disassembled and wiped free of any water or ice, and each impinger will be weighed. A volume of 200 ml of 0.1N NaOH will be measured and used to rinse the probe, first three impingers and connecting glassware. The nozzle and probe will be removed, rinsed and brushed with 0.1N NaOH into an amber glass sample jar (container no. 1). After agitating each impinger the contents will be transferred to a graduated cylinder. Each of the first three impingers will be rinsed with approximately 30 ml of 0.1 N NaOH two additional times. All connecting glassware will also be rinsed with the remaining NaOH and added to the graduated cylinder. The final volume will be recorded and the sample placed in container no. 1.

A sample blank will be collected in an amber glass container adding a volume of 0.1N NaOH equal to the volume of the sample container.

Sample Shipment and Storage

All samples will be labeled and assigned chain-of-custody forms in the field. The samples will then be returned to the LFR office for refrigerated storage prior to analysis. Samples will be shipped in an iced cooler.

Analytical Procedures

Sample preparation and analysis will be performed in accordance with EPA Reference Method 306. Immediately prior to analysis, the samples will be filtered through a 0.45 micron filter. The samples will then be preconcentrated and analyzed via IC/PCR.

Data Reduction/Calculations

The field data and analytical results will be subject to the data reduction and calculation methodologies specified in U.S. EPA Reference Methods 1, 2, 4, 5, and 306. The resultant calculations will be included in emission factor development calculations.

PM2.5

Summary

PM2.5 emissions will be determined in accordance with USEPA Reference Method 201A, Determination of PM10 Emissions (Constant Sample Rate Method) and USEPA Reference Method 202, Determination of Condensable Particulate Emissions From Stationary Sources.

Suspended (filterable) and condensable particulate matter with an aerodynamic particle size of 2.5 microns or less will be separated from the sampled gas with an in-stack cyclone and collected on a glass fiber filter and in water. Recovered samples will then be analyzed gravimetrically for particulate in accordance with Method 5 and Method 202.

The same methods and procedures will be followed as for PM10 emissions (Section 5.2) except that the in-stack cyclone will separate PM2.5 instead of PM10.

Quality Assurance/Quality Control Procedures

To validate the precision of sampling techniques and ensure valid data are collected, several quality assurance and quality control (QA/QC) techniques will be implemented. Such techniques will include conducting tests at each condition in triplicate. USEPA test methods and associated QA/QC procedures will be followed for sampling and analysis of welding emissions. Other QA/QC measures will include only the use of experienced welders to complete the test blasting.

This test plan was developed in accordance with the principles and recommendations outlined in the U.S. EPA *Quality Assurance Handbook for Air Pollution Measurement Systems*. The following sections outline LFR's stack sampling quality assurance (QA) procedures.

Chain of Custody

Each sample requires its own chain-of-custody (COC)/request-for-analysis form. The COC must be completed to ensure the integrity of the samples collected. Before relinquishing the sample, the project manager must complete a COC listing his/her name, the name of the person receiving the results, the LFR project number, the sample description (media), the sample date/time, and the name of the person who performed the sampling.

The COC must also identify the source of the sample, and describe the sample container and the preservative (if any). Additional comments or notes can be placed in the designated space on the COC.

Calibration Data

All pre-test calibration data for sampling and equipment will be available at the time of testing. Copies of all calibration data will be included in the final report.

Calibration Procedures

Detailed standard operating procedures (SOPs) for applicable equipment and instrumentation are documented in LFR's Quality Assurance/Quality Control Plan. These procedures are summarized below.

Pitot Tubes

All S-Type pitot tubes will initially be provided by the manufacturer in accordance with the specifications listed in U.S. EPA Reference Method 2.1. Before each use, a visual inspection of the pitot tube will be made to verify that the face openings are in alignment with the specifications shown in Figure 2-2 and 2-3 of U.S. EPA Method 2. All pitot tubes will be calibrated annually in accordance with Sections 4.1.3 through 4.1.5 of U.S. EPA Method 2.

An identification number will be assigned to a calibrated pitot tube. If the pitot tube is not marked, a baseline coefficient of 0.84 will be assigned.

Dry Gas Meters

A dry gas meter will be used as the calibration standard, in accordance with U.S. EPA Reference Method 5, Section 5.3. The calibration meter will be kept in the laboratory solely for the purpose of calibrating the dry gas meters used in the field, and will be re-calibrated annually against a bell prover.

The dry gas meter will be calibrated before and after each use. If the dry gas meter coefficients obtained before and after the test series differ by more than 5 percent, the calculations for the test series will be performed using the coefficient that gives the lower value of sample volume.

Nozzles

Each probe nozzle will be visually inspected before being used in the field. The nozzle's internal diameter will be calibrated using U.S. EPA Method 5.1. When the nozzle becomes out-of-round, chipped, or corroded, it will be reshaped, sharpened, and re-calibrated before use. Each nozzle will be permanently identified.

Thermocouples

Thermocouples are calibrated by immersing them side-by-side with a reference mercury-in-glass thermometer. The thermocouples are consecutively immersed in an ice bath, boiling water, and a hot oil bath. If the absolute temperature readings between the thermocouple and the reference thermometer agree within ±1.5 percent at all three calibration points, the actual thermocouple reading is considered acceptable.

Field Data Sheets

Copies of data sheets to be utilized in the field during the sampling program are included in Appendix B.

Calculations

As specified, in Section 5.0, emission rates will be calculated for TSP, PM10, PM2.5 and various metals in accordance with the respective test methods. These data along with the usage data for the rods/wires will be utilized for emission factor development (Task 4 of the project). The emission factors will be a mass emission rate per unit measure of rod/wire utilized.

Test schedule

It is anticipated that one test condition per day will be completed. With eight total conditions to be tested, it is anticipated that the test program will last approximately two weeks, including setup and breakdown time. The testing will likely take place in September 1999.

Test limitations

It is expected that reasonable and accurate data will be collected from this test program. However, there are certain limitations on this type of approach. The primary limitation will be the ability to collect, exhaust and measure the contaminants of concern. Although the proposed methods will likely result in accurate measurement of contaminants, great care will be taken to ensure sufficient sample volumes are collected to meet analytical detection limits. This may result in the need for field modifications to test parameters. With careful sample collection procedures and adequate sampling times, the effects of these potential limitations should be minimized.

Task 3: Report on Construction of Sample Collection Equipment

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Task 3: Report on Construction of Sample Collection Equipment

Introduction

Emission factor development testing was completed at the Atlantic Marine Inc. (AMI) Mayport facility in Jacksonville, Florida from October 4 through 13, 1999. In order to develop emission factors for shipyard welding operations, it was necessary to design and construct a facility to collect and exhaust welding fumes and allow collection of exhaust samples. Welding was conducted within the test facility and fumes were vented through the system exhaust. An existing paint spray booth was utilized as the test facility. This spray booth was modified to facilitate complete fume collection.

Based on the shipyard survey performed as part of Task 1: Selection of Welding Process and Type Rod/Wire (Deliverable No. 1), Two different welding methods were selected for the test program using a total of eight different types of rods and wire. These methods included submerged arc welding (SAW) and shielded metal arc welding (SMAW). The survey revealed that these were the predominant welding processes being conducted at shipyards utilizing rods and wires containing significant hazardous air pollutant (HAP) components. Table 1 summarizes the combinations of welding processes and rods/wire that were utilized for emission factor development. Welding was completed within the spray booth and the exhaust was sampled for various components using USEPA sampling methods.

Table 1
Rods/Wires and Welding Processes Selected
for Emission Factor Testing

Rod/Wire American Welding	Welding Process
E308-16, E308L-16	Shielded Metal Arc Welding
E309-16	Shielded Metal Arc Welding
E308-17, E308L-17	Shielded Metal Arc Welding
E309-17, E309L-17	Shielded Metal Arc Welding
E316-16, E316L-16	Shielded Metal Arc Welding
E308-16, E308H-16	Shielded Metal Arc Welding
ER309, ER309L	Submerged Arc Welding
ER316, ER316L	Submerged Arc Welding

Test Facility

The spray booth measured approximately 14 feet wide by 22 feet long by 10 feet high. To configure the spray booth as the sample collection chamber some modifications were made to meet USEPA's requirements for a temporary total enclosure while still allowing safe access for the source sampling team. The spray booth was operated in reverse of its normal configuration with makeup air being supplied through the exhaust stack. An exhaust fan and horizontal duct were attached to the front of the booth at one of the normal makeup air inlet points. All other inlets were blocked off. Approximately 4000 scfm of air was exhausted from the test facility resulting in over 75 air changes per hour. In this configuration, the test facility met the specifications of USEPA Method 204, *Criteria for and Verification of a Permanent or Temporary Total Enclosure* and 100% fume capture was assumed.

The inlet air to the test facility was filtered with standard HVAC filters. The exhaust duct was of horizontal configuration and measured 22 inches square by approximately 32 feet long. Three five-inch diameter sample ports were installed in the vertical portion of the exhaust duct approximately 17 feet downstream of the exhaust blower transition. These ports were used for PM10 and PM2.5 sampling. Three sets of 3-inch ports (5 ports each in the vertical portion of the duct) were also installed in the duct and utilized for total particulate and metals sampling. All sample ports met the criteria of USEPA Method 1, *Sample and Velocity Traverses for Stationary Sources*.

Welding was completed within the test facility by experienced welders and all fumes were vented through the exhaust duct. Sampling equipment was set up along the exhaust duct and samples were collected and analyzed for various components as summarized in Table 2. Total usage of welding rod and wire was tracked and used, along with the source testing data to establish emission factors for the various combinations of welding methods and rods/wires.

Table 2 Summary of Analytical Parameters for Emission Factor Testing
Particulate matter less than 10 microns (PM10)
Particulate matter less than 2.5 microns (PM2.5)
Total suspended particulate (TSP)
Nickel
Manganese
Lead
Cadmium
Total chromium
Hexavalent chromium

Test Facility and Sample Collection Photographs

Photograph 1: Paint Booth Prior to Modifications

Photograph 2: Test Facility Overview Including Test Chamber, Exhaust Duct

Photograph 3: Test Chamber Exhaust Blower and Exhaust Duct

Photograph 4: Test Chamber Makeup Air Filters

Photograph 5: Test Chamber Interior and Exhaust Duct

Task 4: Report on Collection of Fume Samples

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Task 4: Report on Collection of Fume Samples

Introduction

As discussed in *Deliverable No. 3 – Report on Construction of Sample Collection Equipment,* a test enclosure was fabricated using an existing paint spray booth at the Atlantic Marine, Inc. Mayport facility in Jacksonville, Florida. Welding was conducted within the test chamber with all fumes captured and exhausted through a horizontal 22-inch square exhaust duct. The exhaust duct included sampling ports that met the criteria of USEPA Method 1, *Sample and Velocity Traverses for Stationary Sources*. Additional details on the test enclosure are provided in Deliverable 3. Source sampling equipment was utilized to collect samples from the test enclosure exhaust duct utilizing USEPA Reference Methods. Process details were monitored throughout each test and were used in conjunction with sampling results to develop emission factors for each test condition.

Test Conditions

Welding was conducted by personnel experienced in shipyard welding operations. Various steel components were welded within the test enclosure utilizing shielded metal arc welding (SMAW) and submerged arc welding (SAW) processes. These processes were chosen based on the shipyard survey performed as part of Task 1: Selection of Welding Process and Type Rod/Wire (Deliverable No. 1). The survey revealed that these were the predominant welding processes being conducted at shipyards utilizing rods and wires containing significant HAP components. Welding was conducted with a total of eight different rods/wires, also as identified in Deliverable No. 1.

This section summarizes the combinations of welding processes and rods/wires that were utilized for the emission factor development test program. Specifications for the equipment and rods/wires are also included.

Shielded Metal Arc Welding:

Equipment: Miller Electric Manufacturing Co.

SRH-444 Constant Current DC Arc Welding Power Source

Welding Conditions: 36 V, 150 A

Table 1: Shielded Metal Arc Welding Rod Specifications

Rod Type	**Manufacturer**	**Rod Diameter**	**Test No.**
E308-16, E308L-16	Lincoln Electric – Red Baron	1/8”	1
E309-16	Lincoln Electric – Red Baron	1/8”	2
E308-17, E308L-17	Eutectic Corporation	1/8”	6
E309-17, E309L-17	Lincoln Electric – Blue Max Universal Wire Works	5/32”	3

E316-16, E316L-16	Lincoln Electric – Red Baron	1/8”	4
E308-16, E308H-16	Techalloy Company	1/8”	8

Submerged Arc Welding:

Equipment: Lincoln Electric

IDEALARC DC-600 Constant Voltage/Constant Current DC Arc Welder

Lincoln LN-9 Wire Feeder

Welding Conditions: 32 V, 300 A

Flux Type: Lincolnweld ST-100 Agglomerated Alloy Flux

Table 2: Submerged Arc Welding Wire Specifications

Wire Type	**Manufacturer**	**Wire Diameter**	**Test No.**
ER309, ER309L	Lincoln Electric – Blue Max	5/64”	7
ER316, ER316L	Lincoln Electric – Blue Max	5/64”	5

Test procedures

Welding was conducted under controlled test conditions within the test enclosure. Metal parts were welded utilizing the combination of methods and rods/wires described above. Each test run was approximately two hours in duration. Three test runs were completed for each condition with the exception of submerged arc welding where only two tests were completed for each condition. U.S. EPA Reference Methods were utilized for sampling the welding fumes within the enclosure exhaust duct. The test methods and contaminants analyzed are summarized in Table 3 followed by brief summaries of each method. Additional details on test methods are provided in the Shipyard Welding Emission Factor Development Test Plan (Deliverable 2).

TABLE 3: Parameters and Test Methods Utilized for Emission Factor Development

Parameter	Test Method
Flow Rate	U.S. EPA Reference Method 1, *Sample and Velocity Traverses for Stationary Sources*
	U.S. EPA Reference Method 2, *Determination of Stack Gas Velocity and Volumetric Flow Rate (Type-S Pitot Tube)*

TABLE 3: Parameters and Test Methods Utilized for Emission Factor Development	
Parameter	Test Method
Moisture	U.S. EPA Reference Method 4, *Determination of Moisture Content in Stack Gas*
Total Suspended Particulate	U.S. EPA Reference Method 5, *Determination of Particulate Emissions from Stationary Sources*
Particulate Matter less than 10 microns and less than 2.5 microns	Modified version of U.S. EPA Reference Method 201A, *Determination of PM10 Emissions (Constant Sampling Rate Procedure)*
	U.S. EPA Reference Method 202, *Determination of Condensible Particulate Emissions from Stationary Sources*
	U.S. EPA Draft Method for Determination of PM10 and PM2.5 Emissions(Constant Sampling Rate Procedure; June 8, 1999)
Metals – Nickel, Manganese, Lead, Cadmium, and Total Chromium	U.S. EPA Reference Method 29, *Determination of Metals Emissions from Stationary Sources*
Metals – Hexavalent Chromium	U.S. EPA Reference Method 306, *Determination of Chromium Emissions from Decorative and Hard Chromium Electroplating and Anodizing Operations*

Total Particulate

Particulate emissions were determined in accordance with USEPA Reference Method 5, *Determination of Particulate Emissions from Stationary Sources*. In this method, gaseous and particulate pollutants were withdrawn isokinetically and collected on a glass fiber filter. The particulate mass, which includes any material that condenses at or above the filtration temperature, was determined gravimetrically after removal of uncombined water.

PM10/PM2.5

PM10 and PM2.5 emissions were determined in accordance with a modified version of USEPA Reference Method 201A, *Determination of PM10 Emissions (Constant Sample Rate Method)* and USEPA Reference Method 202, *Determination of Condensible Particulate Emissions from Stationary Sources.* In addition, the USEPA Draft Method for Determination of PM10 and PM2.5 Emissions (June 8, 1999) was utilized.

Using these isokinetic methods, suspended (filterable) particulate matter with an aerodynamic particle size of 10 microns and 2.5 microns or less was separated from the sampled gas with combined in-stack cyclones and collected on a glass fiber filter. Condensible particulate matter was collected in water impingers. Recovered samples from the cyclone and filter were analyzed gravimetrically for particulate in accordance with Method 5 and Method 202.

Metals (excluding hexavalent chromium)

The enclosure exhaust was sampled for metal emissions (other than hexavalent chromium) in accordance USEPA Reference Method 29, *Determination of Metals Emissions from Stationary Sources*. With this method, metals in the sample gas were withdrawn isokinetically and collected in the sample train on a filter and in acidic impinger reagents. Recovered samples were digested and analyzed for total chromium (Cr), cadmium (Cd), nickel (Ni), manganese (Mn), and lead (Pb) in accordance with Method 29.

Hexavalent Chromium

Hexavalent chromium emissions were determined in accordance with USEPA Reference Method 306. With this method, gaseous pollutants were withdrawn isokinetically and collected in an alkaline solution. The collected samples were analyzed by an ion chromatograph equipped with a post-column reactor (IC/PCR) for hexavalent chromium.

Calculations

The total mass of rod/wire consumed was measured and recorded for each test. Emission rates were calculated for TSP, PM10, PM2.5, and various metals in accordance with the respective test methods. These data, along with the usage data for the rods/wires, were utilized for emission factor development. Emission factors were calculated based on a mass emission rate per unit measure of rod/wire utilized.

Task 5: Report on Chemical Analysis of Fume Samples

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Task 5: Report on Chemical Analysis of Fume Samples

Introduction

Fume samples were analyzed in accordance with the USEPA Reference Methods specified in *Deliverable No. 4 – Report on Collection of Fume Samples*. Using the analytical data, source sampling data and measured exhaust duct flow rate, mass emission rates were calculated for each test. These data, along with the rod/wire use amounts were used to calculate emission factors for each test. The emission factors are presented on a mass emission rate per mass of rod consumed basis.

Analytical Results

The analytical results are summarized in the attached tables. Table 1 summarizes the calculated emission factor for each test run on a pound of emissions per pound of rod/wire consumed basis. Tables 2 through 7 summarize the analytical and other raw test and process data that were utilized to derive the emission factors for each testing parameter.

Particulate emissions typically consist of a filterable fraction (front-half) and condensible fraction (back-half). Therefore the data presented in Table 1 (Summary Table) include the total of the condensible and filterable fractions for total suspended particulate (TSP), particulate matter less than 10 microns (PM10) and particulate matter less than 2.5 microns (PM2.5). Table 3 represents the condensible fraction of TSP, PM10 and PM2.5. For example, the TSP emission factor in Table 1 is based on the total of the TSP front-half emission factor from Table 2 and the back-half emission factor from Table 3. The PM2.5 emission factor is the total of the front-half emission factor from Table 4 and the back-half emission factor from Table 3. The PM10 emission factor is the sum of the front-half emission factor from Table 5, the back-half emission factor from Table 3 and the PM2.5 front-half factor from Table 4. The front-half PM2.5 emission factor is added to the PM10 total since PM2.5 is considered to be PM10 since the diameters of these particles are less than 10 microns.

The PM10 data presented in Table 7 does not include PM2.5 since the combined PM10/PM2.5 sample head uses 2 cyclones in series to separate particles greater than 10 microns and greater than 2.5 microns. The Table 7 data represent the PM2.5 cyclone catch, which includes particles between 2.5 and 10 microns. Therefore the PM2.5 numbers are added to the PM10 data to accurately quantify PM10 emission factors.

The analytical results for metals (other than hexavalent chromium) presented in Table 6 include both the filterable and condensible fractions. Both fractions were digested in the laboratory, combined and analyzed as a single sample. Since the hexavalent chromium sampling method does not require the use of a filter, only the back-half samples were analyzed.

Some anomalies in the data exist for Test No. 6, Runs 2 and 3 (submerged arc welding, E308-17, E308L-17) where the TSP emission factors are less than those for PM10 and PM2.5. This is not possible since TSP represents total particulates and PM10 and PM2.5 represent a certain fraction of TSP. These anomalies are likely due to sampling and analytical limitations that are sometimes experienced with low emission rates such as those demonstrated during this sampling program. In addition, it is commonly accepted that welding fume consists of a high percentage of small diameter particulate matter. Most of the data for the other tests conducted during this program support that belief with very small differences between TSP and PM10 emission factors. A similar disparity exists for Test 8, Run 1 (submerged arc welding, E308-17, E308H-17) where TSP numbers are slightly higher than PM10. It is not believed that these anomalies affect the overall validity of the test data. It should also be noted that the analytical results for cadmium emissions were below method detection limits for several runs. In these cases, the detection limits were used to calculate emission factors.

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Table 1
Summary of Test Data
NSRP Welding Emission Factor Development

Test No.	Run No.	Date	Welding Process	Rod/ Wire Type	Emission Factor (lb emissions/lb rod/wire consumed)								
					TSP	PM10	PM2.5	Cadmium	Total Chromium	Lead	Manganese	Nickel	Hexavalent Chromium
1	1	10/4/99	SMAW	E308-16,E308L-16	4.812E-02	1.762E-02	8.527E-03	2.020E-06	7.071E-04	3.199E-05	3.535E-04	5.724E-05	1.499E-04
	2	10/4/99	SMAW	E308-16,E308L-16	3.375E-02	3.212E-02	3.042E-02	2.444E-07	4.888E-04	7.332E-06	3.666E-04	3.492E-05	1.363E-04
	3	10/5/99	SMAW	E308-16,E308L-16	5.359E-02	3.283E-02	3.283E-02	6.198E-07	5.950E-04	9.545E-06	2.975E-04	4.339E-05	1.508E-04
2	1	10/5/99	SMAW	E309-16	3.884E-02	3.009E-02	2.914E-02	3.881E-07	8.193E-04	7.906E-06	4.025E-04	6.037E-05	3.060E-06
	2	10/5/99	SMAW	E309-16	4.109E-02	3.703E-02	3.703E-02	4.475E-07	6.572E-04	6.992E-06	3.076E-04	5.593E-05	1.630E-04
	3	10/6/99	SMAW	E309-16	3.178E-02	3.329E-02	3.248E-02	4.301E-07	7.487E-04	7.009E-06	3.664E-04	6.532E-05	9.350E-05
3	1	10/6/99	SMAW	E309-17, E309L-17	3.326E-02	2.269E-02	2.120E-02	8.427E-07	5.306E-04	5.618E-06	3.225E-04	4.161E-05	1.517E-04
	2	10/6/99	SMAW	E309-17, E309L-17	2.012E-02	1.630E-02	1.551E-02	1.117E-06	6.610E-04	5.865E-06	4.003E-04	5.306E-05	9.189E-05
	3	10/11/99	SMAW	E309-17, E309L-17	2.203E-02	2.057E-02	2.035E-02	1.000E-06	8.604E-04	8.904E-06	5.903E-04	6.503E-05	3.198E-06
4	1*	10/7/99	SMAW	E316-16, E316L-16	4.844E-02	3.663E-02	3.663E-02	1.412E-07	9.316E-04	9.175E-06	4.517E-04	8.328E-05	2.187E-04
	2*	10/7/99	SMAW	E316-16, E316L-16	1.053E-01	3.587E-02	3.439E-02	1.204E-07	1.011E-03	6.380E-06	5.056E-04	9.630E-05	2.281E-04
	3*	10/7/99	SMAW	E316-16, E316L-16	1.516E-01	1.759E-02	1.630E-02	1.026E-07	5.436E-04	5.436E-06	2.975E-04	5.334E-05	1.236E-04
5	1	10/8/99	SAW	ER316, ER316L	8.948E-03	8.805E-03	8.650E-03	7.635E-08	8.399E-06	1.489E-06	9.544E-05	3.818E-06	1.834E-06
	2	10/8/99	SAW	ER316, ER316L	6.954E-03	6.711E-03	6.406E-03	1.140E-07	5.700E-06	4.275E-07	3.563E-05	4.275E-06	1.158E-06
6	1*	10/8/99	SMAW	E308-17,E308L-17	2.602E-02	2.417E-02	2.417E-02	1.148E-07	3.675E-04	9.073E-06	3.445E-04	3.101E-05	7.490E-05
	2	10/11/99	SMAW	E308-17,E308L-17	2.448E-02	2.504E-02	2.291E-02	1.573E-07	6.710E-04	1.573E-05	5.871E-04	6.920E-05	1.200E-04
	3	10/11/99	SMAW	E308-17,E308L-17	2.968E-02	3.208E-02	3.135E-02	3.909E-07	6.553E-04	1.150E-05	5.749E-04	5.404E-05	1.268E-04
7	1	10/9/99	SAW	ER309, ER309L	1.021E-02	9.623E-03	9.623E-03	5.572E-07	5.756E-06	3.368E-06	3.613E-05	3.735E-06	1.333E-06
	2	10/9/99	SAW	ER309, ER309L	2.504E-02	2.367E-02	2.123E-02	3.651E-06	1.912E-05	9.215E-06	1.443E-04	1.269E-05	4.332E-06
8	1*	10/12/99	SMAW	E308-17, E308H-17	2.812E-02	2.825E-02	2.686E-02	1.166E-07	1.143E-03	4.782E-06	8.164E-04	2.099E-04	2.204E-04
	2*	10/12/99	SMAW	E308-17, E308H-17	2.983E-02	2.478E-02	2.455E-02	1.194E-07	1.194E-03	4.776E-06	8.596E-04	2.269E-04	1.717E-04
	3*	10/12/99	SMAW	E308-17, E308H-17	3.533E-02	3.012E-02	2.987E-02	1.266E-07	1.202E-03	4.809E-06	8.606E-04	2.278E-04	1.628E-04

* Cadmium Results Less than Method Detection Limit (0.10 ug). MDL Used for Emission Factor Development

Table 2
Method 5 - TSP - Filters (front half)
NSRP Welding Emission Factor Development
Analytical Results

AirRecon Run No.	Method 5 TSP Date	LFR Run No. Test No.	LFR Run No. Run No.	Welding Process	Rod/ Wire Type	Analytical Results (gms)	Meter Box (dscf)	Air Volume (dscfm)	Test Length (min)	Mass Rods Used (lb)	Emission Factor (lb/lb rod)
1	**10/4/99**	1	1	SMAW	E308-16,E308L-16	0.0149	80.123	3821	135	7.133	0.0296
2	**10/4/99**	1	2	SMAW	E308-16,E308L-16	0.0089	78.719	3880	125	6.372	0.0190
3	**10/5/99**	1	3	SMAW	E308-16,E308L-16	0.0214	85.878	4124	126	8.454	0.0338
4	**10/5/99**	2	1	SMAW	E309-16	0.0117	85.380	4075	127	7.179	0.0218
5	**10/5/99**	2	2	SMAW	E309-16	0.0101	80.868	3965	125	7.373	0.0185
6	**10/6/99**	2	3	SMAW	E309-16	0.0084	80.130	3940	122	6.181	0.0180
7	**10/6/99**	3	1	SMAW	E309-17, E309L-17	0.0108	79.953	3933	124	9.543	0.0152
8	**10/6/99**	3	2	SMAW	E309-17, E309L-17	0.0115	81.573	3983	126	10.811	0.0144
17	**10/11/99**	3	3	SMAW	E309-17, E309L-17	0.0118	85.062	4118	127	9.502	0.0168
9	**10/7/99**	4	1	SMAW	E316-16, E316L-16	0.0171	90.035	4279	129	7.568	0.0305
10	**10/7/99**	4	2	SMAW	E316-16, E316L-16	0.0526	84.992	4108	127	8.000	0.0890
11	**10/7/99**	4	3	SMAW	E316-16, E316L-16	0.0967	86.599	4176	126	9.525	0.1360
13	**10/8/99**	5	1	SAW	ER316, ER316L	0.0105	84.588	4101	125	26.000	0.0054
14	**10/8/99**	5	2	SAW	ER316, ER316L	0.0050	86.221	4137	123	26.500	0.0025
12	**10/8/99**	6	1	SMAW	E308-17,E308L-17	0.0075	87.888	4218	126	8.576	0.0117
18	**10/11/99**	6	2	SMAW	E308-17,E308L-17	0.0103	82.486	4018	121	8.503	0.0157
19	**10/11/99**	6	3	SMAW	E308-17,E308L-17	0.0087	83.211	4050	125	8.401	0.0139
15	**10/9/99**	7	1	SAW	ER309, ER309L	0.0035	84.734	4141	127	16.500	0.0029
16	**10/9/99**	7	2	SAW	ER309, ER309L	0.0040	81.268	3992	119	5.500	0.0094
20	**10/12/99**	8	1	SMAW	E308-17, E308H-17	0.0122	84.179	4036	125	8.343	0.0193
21	**10/12/99**	8	2	SMAW	E308-17, E308H-17	0.0124	80.943	3934	124	7.931	0.0208
22	**10/12/99**	8	3	SMAW	E308-17, E308H-17	0.0119	83.714	4110	125	7.801	0.0206
23	**10/13/99**	Background	1	NA	NA	0.0028	82.453	3973			
Blank	**10/12/99**	NA	NA	NA	NA						

Table 3
Method 201 - Condensibles (back half)
NSRP Welding Emission Factor Development
Analytical Results

AirRecon Run No.	Method 201 PM 2.5 Date	LFR Run No.		Welding Process	Rod/ Wire Type	Analytical Results (mg)	Meter Box (dscf)	Air Volume (dscfm)	Test Length (min)	Mass Rods Used (lb)	Emission Factor (lb/lb rod)
		Test No.	Run No.								
1	**10/4/99**	1	1	SMAW	E308-16,E308L-16	6.50	54.298	3699	145	7.662	0.0185
2	**10/4/99**	1	2	SMAW	E308-16,E308L-16	5.20	54.337	3572	105	5.353	0.0148
3	**10/5/99**	1	3	SMAW	E308-16,E308L-16	9.30	55.916	3628	124	8.320	0.0198
4	**10/5/99**	2	1	SMAW	E309-16	7.20	59.017	3585	131	7.405	0.0171
5	**10/5/99**	2	2	SMAW	E309-16	10.00	61.994	3745	137	8.081	0.0226
6	**10/6/99**	2	3	SMAW	E309-16	5.10	63.127	3927	137	6.941	0.0138
7	**10/6/99**	3	1	SMAW	E309-17, E309L-17	9.70	58.002	3765	126	9.697	0.0180
8	**10/6/99**	3	2	SMAW	E309-17, E309L-17	3.60	62.667	3859	126	10.811	0.0057
17	**10/11/99**	3	3	SMAW	E309-17, E309L-17	2.40	53.081	3901	117	8.754	0.0052
9	**10/7/99**	4	1	SMAW	E316-16, E316L-16	6.50	53.693	3935	128	7.509	0.0179
10	**10/7/99**	4	2	SMAW	E316-16, E316L-16	6.60	56.469	3992	127	8.000	0.0163
11	**10/7/99**	4	3	SMAW	E316-16, E316L-16	7.30	54.226	3988	126	9.525	0.0157
13	**10/8/99**	5	1	SAW	ER316, ER316L	4.60	54.139	3945	125	26.00	0.0036
14	**10/8/99**	5	2	SAW	ER316, ER316L	5.90	52.903	3937	119	25.60	0.0045
12	**10/8/99**	6	1	SMAW	E308-17,E308L-17	6.00	53.535	3955	121	8.236	0.0144
18	**10/11/99**	6	2	SMAW	E308-17,E308L-17	3.70	51.701	3893	115	8.081	0.0087
19	**10/11/99**	6	3	SMAW	E308-17,E308L-17	6.50	53.604	3971	120	8.065	0.0158
15	**10/9/99**	7	1	SAW	ER309, ER309L	6.00	55.028	3945	121	15.700	0.0073
16	**10/9/99**	7	2	SAW	ER309, ER309L	4.50	54.564	3982	119	5.500	0.0157
20	**10/12/99**	8	1	SMAW	E308-17, E308H-17	3.80	55.564	3895	123	8.209	0.0088
21	**10/12/99**	8	2	SMAW	E308-17, E308H-17	3.80	55.534	3840	122	7.804	0.0091
22	**10/12/99**	8	3	SMAW	E308-17, E308H-17	5.90	54.903	3869	122	7.614	0.0147
23	**10/13/99**	Background	1	NA	NA	3.10	55.119	3916			
Blank	**10/12/99**	NA	NA	NA	NA						

Note: Analytical results are from the impinger catch and impinger rinses, after the PM 2.5 filter

Table 4
Method 201 - PM 2.5 - Filters (front half)
NSRP Welding Emission Factor Development
Analytical Results

AirRecon Run No.	Method 201 PM 2.5 Date	LFR Run No.		Welding Process	Rod/ Wire Type	Analytical Results (gms)	Meter Box (dscf)	Air Volume (dscfm)	Test Length (min)	Mass Rods Used (lb)	Emission Factor (lb/lb rod)
		Test No.	Run No.								
1	**10/4/99**	1	1	SMAW	E308-16,E308L-16	-0.0035	54.298	3699	145	7.662	-0.0099
2	**10/4/99**	1	2	SMAW	E308-16,E308L-16	0.0055	54.337	3572	105	5.353	0.0156
3	**10/5/99**	1	3	SMAW	E308-16,E308L-16	0.0061	55.916	3628	124	8.320	0.0130
4	**10/5/99**	2	1	SMAW	E309-16	0.0051	59.017	3585	131	7.405	0.0121
5	**10/5/99**	2	2	SMAW	E309-16	0.0064	61.994	3745	137	8.081	0.0144
6	**10/6/99**	2	3	SMAW	E309-16	0.0069	63.127	3927	137	6.941	0.0187
7	**10/6/99**	3	1	SMAW	E309-17, E309L-17	0.0017	58.002	3765	126	9.697	0.0032
8	**10/6/99**	3	2	SMAW	E309-17, E309L-17	0.0062	62.667	3859	126	10.811	0.0098
17	**10/11/99**	3	3	SMAW	E309-17, E309L-17	0.0070	53.081	3901	117	8.754	0.0152
9	**10/7/99**	4	1	SMAW	E316-16, E316L-16	0.0068	53.693	3935	128	7.509	0.0187
10	**10/7/99**	4	2	SMAW	E316-16, E316L-16	0.0073	56.469	3992	127	8.000	0.0181
11	**10/7/99**	4	3	SMAW	E316-16, E316L-16	0.0003	54.226	3988	126	9.525	0.0006
13	**10/8/99**	5	1	SAW	ER316, ER316L	0.0066	54.139	3945	125	26.00	0.0051
14	**10/8/99**	5	2	SAW	ER316, ER316L	0.0025	52.903	3937	119	25.60	0.0019
12	**10/8/99**	6	1	SMAW	E308-17,E308L-17	0.0041	53.535	3955	121	8.236	0.0098
18	**10/11/99**	6	2	SMAW	E308-17,E308L-17	0.0060	51.701	3893	115	8.081	0.0142
19	**10/11/99**	6	3	SMAW	E308-17,E308L-17	0.0064	53.604	3971	120	8.065	0.0156
15	**10/9/99**	7	1	SAW	ER309, ER309L	0.0019	55.028	3945	121	15.700	0.0023
16	**10/9/99**	7	2	SAW	ER309, ER309L	0.0016	54.564	3982	119	5.500	0.0056
20	**10/12/99**	8	1	SMAW	E308-17, E308H-17	0.0078	55.564	3895	123	8.209	0.0181
21	**10/12/99**	8	2	SMAW	E308-17, E308H-17	0.0065	55.534	3840	122	7.804	0.0155
22	**10/12/99**	8	3	SMAW	E308-17, E308H-17	0.0061	54.903	3869	122	7.614	0.0152
23	**10/13/99**	Background	1	NA	NA	0.0010	55.119	3916			
Blank	**10/12/99**	NA	NA	NA	NA						

Table 5
Method 201 - PM 10 - Cyclone (front half)
NSRP Welding Emission Factor Development
Analytical Results

AirRecon Run No.	Method 201 PM 10 Date	LFR Run No.		Welding Process	Rod/ Wire Type	Analytical Results (gms)	Meter Box (dscf)	Air Volume (dscfm)	Test Length (min)	Mass Rods Used (lb)	Emission Factor (lb/lb rod)
		Test No.	Run No.								
1	**10/4/99**	1	1	SMAW	E308-16,E308L-16	0.0032	54.298	3699	145	7.662	0.0091
2	**10/4/99**	1	2	SMAW	E308-16,E308L-16	0.0006	54.337	3572	105	5.353	0.0017
3	**10/5/99**	1	3	SMAW	E308-16,E308L-16	0.0000	55.916	3628	124	8.320	0.0000
4	**10/5/99**	2	1	SMAW	E309-16	0.0004	59.017	3585	131	7.405	0.0009
5	**10/5/99**	2	2	SMAW	E309-16	0.0000	61.994	3745	137	8.081	0.0000
6	**10/6/99**	2	3	SMAW	E309-16	0.0003	63.127	3927	137	6.941	0.0008
7	**10/6/99**	3	1	SMAW	E309-17, E309L-17	0.0008	58.002	3765	126	9.697	0.0015
8	**10/6/99**	3	2	SMAW	E309-17, E309L-17	0.0005	62.667	3859	126	10.811	0.0008
17	**10/11/99**	3	3	SMAW	E309-17, E309L-17	0.0001	53.081	3901	117	8.754	0.0002
9	**10/7/99**	4	1	SMAW	E316-16, E316L-16	0.0000	53.693	3935	128	7.509	0.0000
10	**10/7/99**	4	2	SMAW	E316-16, E316L-16	0.0006	56.469	3992	127	8.000	0.0015
11	**10/7/99**	4	3	SMAW	E316-16, E316L-16	0.0006	54.226	3988	126	9.525	0.0013
13	**10/8/99**	5	1	SAW	ER316, ER316L	0.0002	54.139	3945	125	26.00	0.0002
14	**10/8/99**	5	2	SAW	ER316, ER316L	0.0004	52.903	3937	119	25.60	0.0003
12	**10/8/99**	6	1	SMAW	E308-17,E308L-17	0.0000	53.535	3955	121	8.236	0.0000
18	**10/11/99**	6	2	SMAW	E308-17,E308L-17	0.0009	51.701	3893	115	8.081	0.0021
19	**10/11/99**	6	3	SMAW	E308-17,E308L-17	0.0003	53.604	3971	120	8.065	0.0007
15	**10/9/99**	7	1	SAW	ER309, ER309L	0.0000	55.028	3945	121	15.700	0.0000
16	**10/9/99**	7	2	SAW	ER309, ER309L	0.0007	54.564	3982	119	5.500	0.0024
20	**10/12/99**	8	1	SMAW	E308-17, E308H-17	0.0006	55.564	3895	123	8.209	0.0014
21	**10/12/99**	8	2	SMAW	E308-17, E308H-17	0.0001	55.534	3840	122	7.804	0.0002
22	**10/12/99**	8	3	SMAW	E308-17, E308H-17	0.0001	54.903	3869	122	7.614	0.0002
23	**10/13/99**	Background	1	NA	NA	0.0017	55.119	3916			
Blank	**10/12/99**	NA	NA	NA	NA						

Table 6
Method 29 - Metals
NSRP Welding Emission Factor Development
Analytical Results

AirRecon Run No.	Method 5 TSP Date	LFR Run No. Test No.	LFR Run No. Run No.	Welding Process	Rod/ Wire Type	Analytical Results Cadmium (ug)	Analytical Results Chromium (ug)	Analytical Results Lead (ug)	Analytical Results Manganese (ug)	Analytical Results Nickel (ug)	Meter Box (dscf)	Air Volume (dscfm)	Test Length (min)	Mass Rods Used (lb)	Emission Factors Cadmium (lb/lb rod)	Emission Factors Chromium (lb/lb rod)	Emission Factors Lead (lb/lb rod)	Emission Factors Manganese (lb/lb rod)	Emission Factors Nickel (lb/lb rod)
1	**10/4/99**	1	1	SMAW	E308-16,E308L-16	1.2	420	19	210	34	91.828	3705	135	7.133	0.000002	0.00071	0.00003	0.00035	0.00006
2	**10/4/99**	1	2	SMAW	E308-16,E308L-16	0.14	280	4.2	210	20	92.153	3720	125	6.372	0.0000002	0.00049	0.00001	0.00037	0.00003
3	**10/5/99**	1	3	SMAW	E308-16,E308L-16	0.5	480	7.7	240	35	107.319	4049	126	8.454	0.000001	0.00060	0.00001	0.00030	0.00004
4	**10/5/99**	2	1	SMAW	E309-16	0.27	570	5.5	280	42	108.773	4009	127	7.179	0.0000004	0.00082	0.00001	0.00040	0.00006
5	**10/5/99**	2	2	SMAW	E309-16	0.32	470	5	220	40	102.881	3849	125	7.373	0.0000004	0.00066	0.00001	0.00031	0.00006
6	**10/6/99**	2	3	SMAW	E309-16	0.27	470	4.4	230	41	106.527	3900	122	6.181	0.0000004	0.00075	0.00001	0.00037	0.00007
7	**10/6/99**	3	1	SMAW	E309-17, E309L-17	0.81	510	5.4	310	40	104.164	3783	124	9.543	0.000001	0.00053	0.00001	0.00032	0.00004
8	**10/6/99**	3	2	SMAW	E309-17, E309L-17	1.2	710	6.3	430	57	107.64	3900	126	10.811	0.000001	0.00066	0.00001	0.00040	0.00005
17	**10/11/99**	3	3	SMAW	E309-17, E309L-17	1	860	8.9	590	65	121.698	4132	127	9.502	0.000001	0.00086	0.00001	0.00059	0.00007
9*	**10/7/99**	4	1	SMAW	E316-16, E316L-16	0.1	660	6.5	320	59	107.286	4030	129	7.568	0.0000001	0.00093	0.00001	0.00045	0.00008
10*	**10/7/99**	4	2	SMAW	E316-16, E316L-16	0.1	840	5.3	420	80	115.311	3966	127	8.000	0.0000001	0.00101	0.00001	0.00051	0.00010
11*	**10/7/99**	4	3	SMAW	E316-16, E316L-16	0.1	530	5.3	290	52	115.942	4078	126	9.525	0.0000001	0.00054	0.00001	0.00030	0.00005
13	**10/8/99**	5	1	SAW	ER316, ER316L	0.2	22	3.9	250	10	109.19	3933	125	26.000	0.0000001	0.00001	0.000001	0.00010	0.000004
14	**10/8/99**	5	2	SAW	ER316, ER316L	0.32	16	1.2	100	12	117.846	4103	123	26.500	0.0000001	0.00001	0.0000004	0.00004	0.000004
12*	**10/8/99**	6	1	SMAW	E308-17,E308L-17	0.1	320	7.9	300	27	112.139	3976	126	8.576	0.0000001	0.00037	0.00001	0.00034	0.00003
18	**10/11/99**	6	2	SMAW	E308-17,E308L-17	0.15	640	15	560	66	123.22	4118	121	8.503	0.0000002	0.00067	0.00002	0.00059	0.00007
19	**10/11/99**	6	3	SMAW	E308-17,E308L-17	0.34	570	10	500	47	117.663	4124	125	8.401	0.000000	0.00066	0.00001	0.00057	0.00005
15	**10/9/99**	7	1	SAW	ER309, ER309L	0.91	9.4	5.5	59	6.1	115.53	4169	127	16.500	0.000001	0.00001	0.00000	0.00004	0.00000
16	**10/9/99**	7	2	SAW	ER309, ER309L	2.1	11	5.3	83	7.3	111.855	4077	119	5.500	0.000004	0.00002	0.00001	0.00014	0.00001
20*	**10/12/99**	8	1	SMAW	E308-17, E308H-17	0.1	980	4.1	700	180	117.498	4149	125	8.343	0.0000001	0.00114	0.000005	0.00082	0.00021
21*	**10/12/99**	8	2	SMAW	E308-17, E308H-17	0.1	1000	4	720	190	113.427	3929	124	7.931	0.0000001	0.00119	0.000005	0.00086	0.00023
22*	**10/12/99**	8	3	SMAW	E308-17, E308H-17	0.1	950	3.8	680	180	113.103	4052	125	7.801	0.0000001	0.00120	0.000005	0.00086	0.00023
23*	**10/13/99**	Background	1	NA	NA	0.1	13	1.2	18	9.3	113.314	3967	125						
Blank*	**10/12/99**	NA	NA	NA	NA	0.1	1.4	0.57	1.9	1.2									

* = Cadmium Results Less than Method Detection Limit (0.10 ug). MDL Used for Emission Factor Development

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Table 7
Method 306 - Hexavalent / Chromium
NSRP Welding Emission Factor Development
Analytical Results

AirRecon Run No.	Method 306 HexChrome Date	LFR Run No.		Welding Process	Rod/ Wire Type	Analytical Results (ug)	Meter Box (dscf)	Air Volume (dscfm)	Test Length (min)	Mass Rods Used (lb)	Emission Factor (lb/lb rod)
		Test No.	Run No.								
1	**10/4/99**	1	1	SMAW	E308-16,E308L-16	69	71.855	3742	135	7.133	0.00015
2	**10/4/99**	1	2	SMAW	E308-16,E308L-16	60	78.674	4133	125	6.372	0.00014
3	**10/5/99**	1	3	SMAW	E308-16,E308L-16	88	81.927	4274	126	8.454	0.00015
4	**10/5/99**	2	1	SMAW	E309-16	1.6	85.924	4214	127	7.179	0.000003
5	**10/5/99**	2	2	SMAW	E309-16	87	80.447	4033	125	7.373	0.00016
6	**10/6/99**	2	3	SMAW	E309-16	43	79.125	3954	122	6.181	0.00009
7	**10/6/99**	3	1	SMAW	E309-17, E309L-17	97	75.401	4116	124	9.543	0.00015
8	**10/6/99**	3	2	SMAW	E309-17, E309L-17	71	75.061	3781	126	10.811	0.00009
17	**10/11/99**	3	3	SMAW	E309-17, E309L-17	2.1	78.983	4082	127	9.502	0.000003
9	**10/7/99**	4	1	SMAW	E316-16, E316L-16	120	83.349	4043	129	7.568	0.00022
10	**10/7/99**	4	2	SMAW	E316-16, E316L-16	120	75.401	4096	127	8.000	0.00023
11	**10/7/99**	4	3	SMAW	E316-16, E316L-16	83	78.459	4007	126	9.525	0.00012
13	**10/8/99**	5	1	SAW	ER316, ER316L	3.4	78.611	4000	125	26.000	0.000002
14	**10/8/99**	5	2	SAW	ER316, ER316L	2.2	79.148	4070	123	26.500	0.000001
12	**10/8/99**	6	1	SMAW	E308-17,E308L-17	47	83.349	4101	126	8.576	0.00007
18	**10/11/99**	6	2	SMAW	E308-17,E308L-17	76	74.125	3732	121	8.503	0.00012
19	**10/11/99**	6	3	SMAW	E308-17,E308L-17	74	76.947	4018	125	8.401	0.00013
15	**10/9/99**	7	1	SAW	ER309, ER309L	1.6	83.349	4091	127	16.500	0.000001
16	**10/9/99**	7	2	SAW	ER309, ER309L	1.7	76.158	4069	119	5.500	0.000004
20	**10/12/99**	8	1	SMAW	E308-17, E308H-17	130	76.812	3942	125	8.343	0.00022
21	**10/12/99**	8	2	SMAW	E308-17, E308H-17	97	78.417	4028	124	7.931	0.00017
22	**10/12/99**	8	3	SMAW	E308-17, E308H-17	83	79.040	4390	125	7.801	0.00016
23	**10/13/99**	Background	1	NA	NA	2.6	77.026	3923	125		
Blank	**10/12/99**	NA	NA	NA	NA						

Task 6: Final Report

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Task 6: Final Report

Introduction

Welding Processes Background

There are more than 80 different types of welding operations, including brazing, thermal cutting, and gauging, in commercial use. Figure 1 shows a diagram of the major types of welding and the relationship between major variations of each process.

By definition, welding is the process of joining two metal parts by melting the parts at the joint and filling the space with molten metal. In welding and similar operations, such as brazing, thermal cutting, and gauging, the most frequently used method for generating heat is obtained either from an electric arc or a gas-oxygen flame. The most commonly used processes are described below.

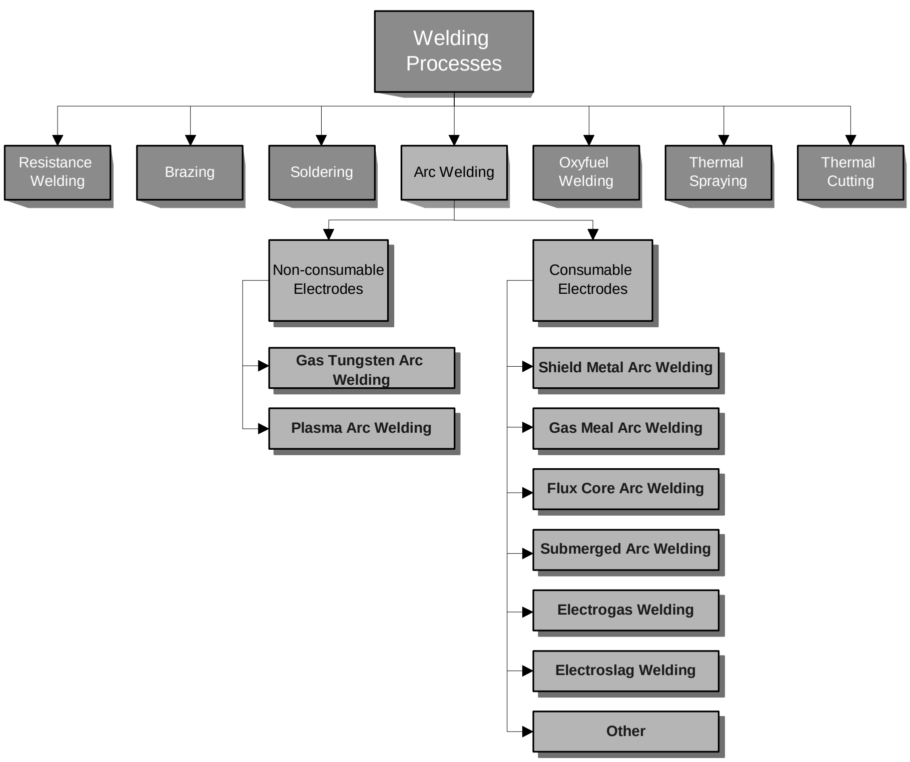


Figure 1

Arc Welding

Electric arc welding, the most frequently used process, includes many different variations that involve various types of electrodes, fluxes, shielding gases, and types of equipment. Electric arc welding can be divided into processes using non-consumable electrodes and consumable electrodes. In electric arc welding, a flow of electricity across the gap from the tip of the welding electrode to the base metal creates the heat needed for melting and joining the metal parts. The electric current melts both the electrode and the base metal at the joint to form a molten pool, which solidifies upon cooling. A description of each of the major types of electric arc welding process is provided below.

Non-consumable Electrode Welding

Gas Tungsten Arc Welding

Gas tungsten arc welding (GTAW) uses a non-consumable tungsten electrode that creates an arc between the electrode and the weld pool. An inert shielding gas is used in the process at no applied pressure. Argon is most commonly used as the shielding gas, and the process may be employed with or without the addition of filler metal.

Advantages of GTAW include its versatility, low equipment costs, control, and weld quality. It is widely used for the welding of light gauge stainless steel and aluminum and root passes in pipe butt joints. The GTAW process can easily be set up as an automated process. Another positive attribute of GTAW is the very low fume formation rate (FFR). The filler wire is fed and melted into the weld pool allowing a lower FFR. This procedure is different from other processes that require the fill material to pass through the arc. Since filler is fed directly to the weld pool, operating variables have little effect on the FFR.

Disadvantages of GTAW are its low speed and deposition rate, which utilizes hot or cold wire feed, and high heat input efficiency. By using shielding gas, these problems can be overcome. The GTAW weld zone is also difficult to shield properly in drafty environments.

Plasma Arc Welding

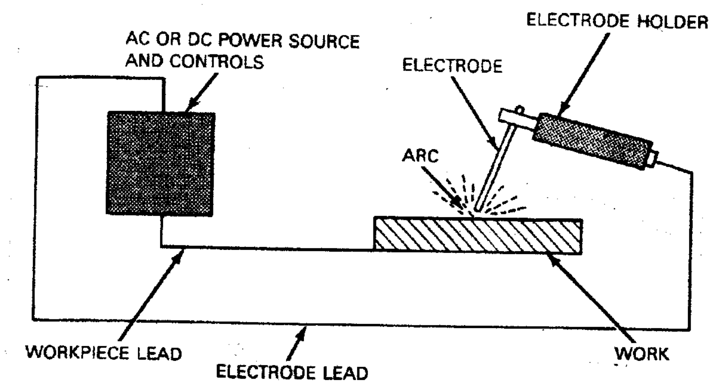
Plasma arc welding (PAW) is a process that fuses work piece metals by heat from an arc between the electrode and the work piece, or from an arc between the electrode and the constricting nozzle. The ionization of the gas issuing from the torch produces plasma. An auxiliary shielding gas made of a single inert gas or a mixture of inert gases generally supplements the plasma. The process may be used with or without a filler metal; pressure is not applied in the system

As in GTAW, plasma arc welding makes use of a non-consumable electrode. A chamber surrounds the electrode on the PAW torch. The chamber fills with gas that is heated by the arc to a temperature where the gas ionizes and conducts electricity. This ionized gas, referred to as plasma, exits from the nozzle at an approximate temperature of 16,700 ^{o}C (30,000 ^{o}F). Plasma arc welding has the ability to join most types of metals in the majority of welding positions. A work piece welded by PAW has a smaller heat-affected zone than GTAW. PAW also operates with better directional control of the arc than GTAW. Compared to other welding processes, PAW uses a lower current to produce a given weld, and there is less shrinkage to the welded area. The major disadvantage of plasma arc welding is the high equipment expense. PAW involves more extensive operator training, more complex welding procedures, and more process control variables, as compared to GTAW. Due to the higher temperatures used in the process, PAW has the disadvantage of higher noise levels and higher ozone production than other processes.

Consumable Electrode Welding

Shielded Metal Arc Welding

Shielded metal arc welding (SMAW) is the most widely used electric arc welding process and the first type to use consumable electrodes. The process also is referred to as manual metal arc welding (MMAW). Shielded metal arc welding uses heat that is produced by an electric arc to melt the metals. The electric arc is maintained between the welding joint at the surface of the base metal and the tip of the covered welding electrode (Figure 2). During operation, the core rod conducts electric current to produce the arc and provides filler metal for the joint. The core of the covered electrode consists of either a solid metal rod of drawn or cast material, or a solid metal rod fabricated by encasing metal powders in a metallic sheath. The electrode covering provides stability to the arc and protects the molten metal by the creation of shielding gases from the vaporization of the electrode cover.



Basic SMAW apparatus.

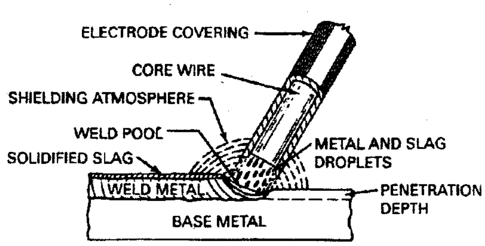


Figure 2

The arc characteristics of the electrode and the mechanical properties, chemical composition, and metallurgical structure of the weld are influenced by the type of shielding used, along with other ingredients within the covering and core wire. Each type of electrode used in SMAW has a different type of electrode covering, depending on the application.

The advantages of the SMAW process include its simplicity, low cost, portability, and the fact that a shielding gas is not needed. One restriction of SMAW is that the deposition cycle is normally less than for processes using continuous electrodes.

Gas Metal Arc Welding

Gas metal arc welding (GMAW) is a consumable electrode welding process that produces an arc between the weld pool and a continuously supplied filler metal. An externally supplied gas is used to shield the arc (Figure 3). GMAW originally was referred to as metal inert gas (MIG) welding because it used an inert gas for shielding. Although it still is sometimes called MIG welding, developments have led to the use of both inert and reactive gases.

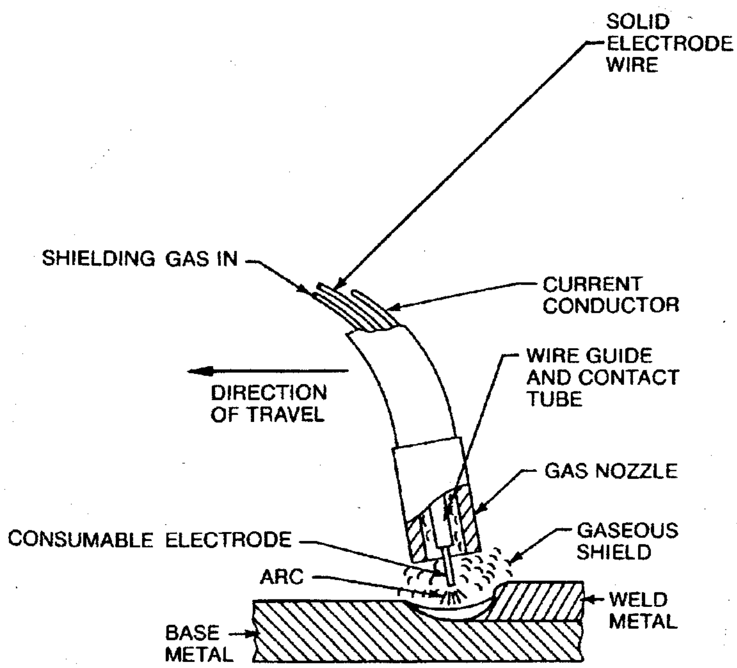
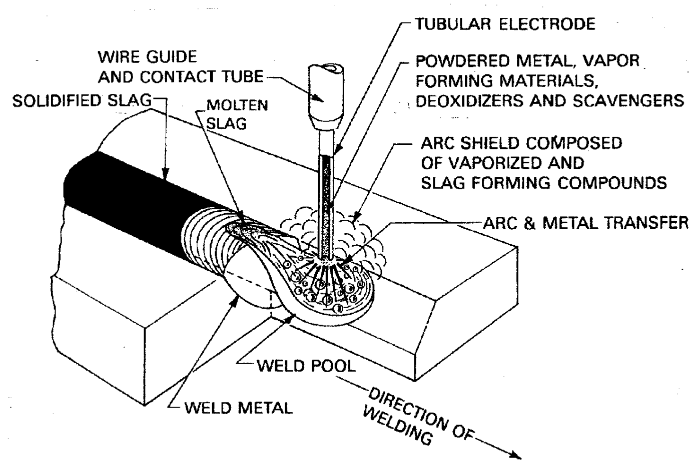


Figure 3

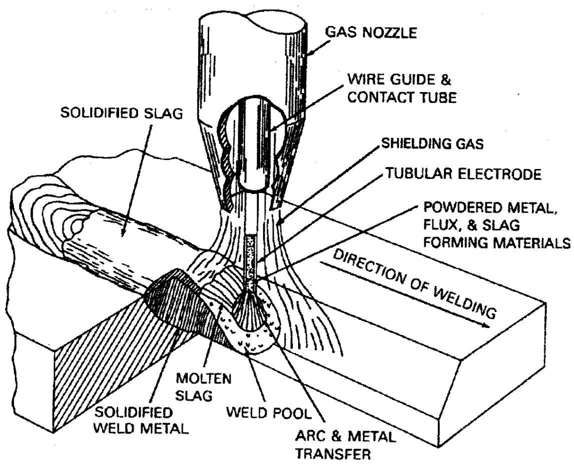
A variation of the GMAW process, referred to as metal-cored electrodes, uses a tubular electrode filled mostly with metallic powders forms. These types of electrodes must use a gas shield to prevent contamination of the molten weld by the atmosphere. The American Welding Society (AWS) considers metal cored electrodes a part of GMAW, although metal cored electrodes are grouped with flux cored electrodes by foreign welding associations. Advantages of GMAW include its ability to be operated in semiautomatic, machine, or automatic modes. It is the only consumable process that can weld all commercially important metals, such as carbon steel, high-strength low alloy steel, stainless steel, nickel alloys, titanium, aluminum, and copper. A weld can be performed in all positions with the proper choice of electrode, shielding gas, and welding variables. Compared with shielded metal arc welding (SMAW), the deposition rates and welding rates are higher for GMAW. Also, the continuous electrode feed makes long welds possible without stops and starts. On the downside, the equipment for GMAW is more complex, more expensive, and less portable than the SMAW process.

Flux Cored Arc Welding

Flux cored arc welding (FCAW) is a consumable electrode welding process that uses shielding from flux contained within the tubular electrode. The heat-generating arc for FCAW operates between a continuous filler metal electrode and the weld pool. Additional shielding may or may not be supplied by an external gas, and the process is used without the application of gas pressure. The flux cored electrode consists of a metal sheath surrounding a core of various powdered materials. The FCAW process is unique in its method of enclosing the fluxing



Shelf-shielded flux cored arc welding (FCAW)



. Gas-shielded flux cored arc welding (FCAW)

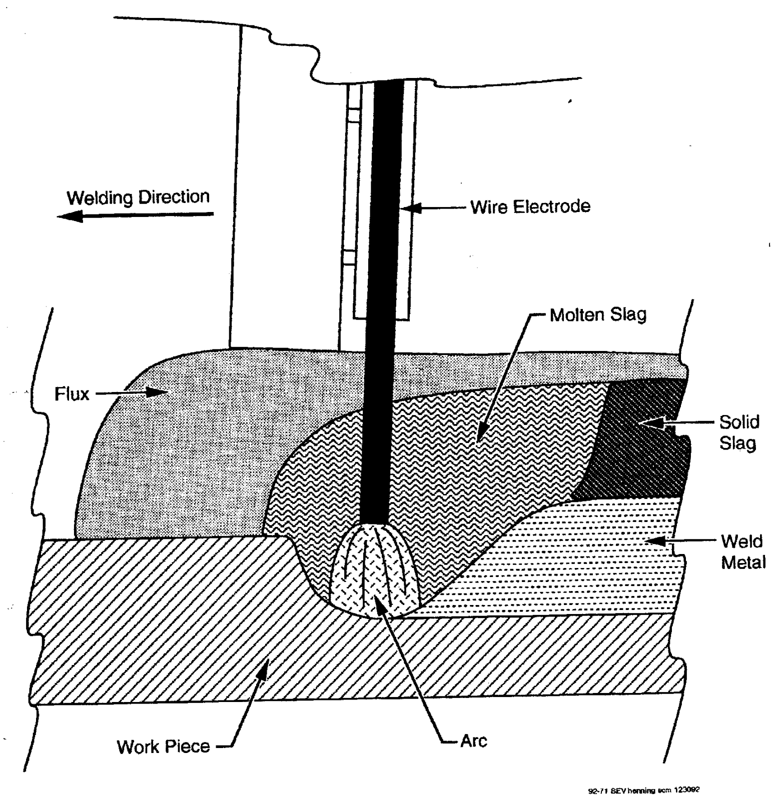
Figure 4

ingredients within the continuously fed electrode. The electrode core material produces a slag cover on the face of the weld bead during the welding process.

The two major process variations of FCAW protect the weld pool from contamination by the atmosphere with different methods. The first method, called self-shielded FCAW, protects the welding pool by the break down and vaporization of the flux core through the heat of the arc (Figure 4). The second FCAW variation uses a shielding gas to protect the welding pool, in addition to protecting the vaporized flux core (Figure 4). Compared to SMAW, the FCAW process provides a high-quality weld metal at lower cost and with less effort by the welder. The process allows for more versatility than submerged arc welding and proves to be more forgiving than gas metal arc welding. On the negative side, the equipment and electrodes for FCAW are more expensive than SMAW, and the slag covering produced must be removed.

Submerged Arc Welding

Submerged arc welding (SAW) produces an arc between a bare metal electrode and the work contained in a blanket of granular fusible flux (Figures 5). The flux submerges the arc and welding pool. Generally, the electrode serves as the filler material, although a welding rod or metal granules may be added. The flux covering the arc in submerged arc welding is an important factor in the process. The flux’s role influences the stability of the arc and the mechanical and chemical properties of the final weld deposit. The quality of the weld is dependent on the handling and care of the flux.



Medium and heavy fabrication industries use the SAW process for fillet and main butt joints in pipe, cylinders, pressure vessels, columns, and beams. Generally, the welding head is fully automatic and mounted on a manipulator or carriage; however, for fillet welding, hand held torches are available. Although SAW is limited to the down hand and horizontal positions, these positions can be utilized by informed design and job positioning. The process is also restricted by the high proportion of time needed to align the torch with the joint.

Figure 5

Welding Emissions Background

The main pollutants of concern generated during welding operations are particulate matter and particulate phase hazardous air pollutants. Only electric arc welding generates pollutants in quantities of major concern. Resistance welding using certain materials also may generate hazardous pollutants. Due to the lower temperatures of the other welding processes, fewer fumes are released.

The quantity of emissions released depends largely on the type of welding process used and its operating conditions. Depending on the choice of electrode and its diameter and composition, emissions are reduced or increased. The work piece composition also affects the quantity of fume released. Coatings on the work piece generate organic and metallic fumes (e.g., galvanized coatings, cleaners, oils, paints, etc.), depending on the particular application. Operating conditions that influence fume emissions include travel speed, voltage, current, arc length, polarity, welding position, electrode angle, and deposition rate.

The welding fume is formed by the vaporization and recondensation of metallic elements upon cooling in ambient air. As such, the particulate matter produced is generally submicron in size with approximately 50% to 75% of the particles having diameters in the range of 0.4 to 0.8 µm. The amount of the emissions generated can vary substantially from process to process.

The elemental composition of the fume varies with the electrode and work piece composition. Hazardous metals listed in the 1990 Clean Air Act Amendments, which have been detected in welding fume include manganese, nickel, chromium, cobalt, and lead. Additionally, the hexavalent form of chrome (Chrome $^{+}$6) is also found in some welding fume emissions. The emissions of toxic air contaminates during welding have potential adverse human health impacts. Occupational exposures to welding fumes are typically controlled with ventilation and personal protective equipment. Environmental exposures are more difficult to define and potential health impacts are usually predicated using computer dispersion models and health risk assessments. As the results of the dispersion models (and therefore the health risk assessment) are directly dependent upon the emission rate of a contaminant, it is important to quantify the emissions factors of the various toxic air contaminates as accurately as possible.

Study Parameters

The study conducted for this project consisted of several distinct tasks, with each task predicated on the prior completed task(s). The complete results of each task are the subject of an individual Task Report, the totality of which comprises the complete project report. For the purpose of Task Six, which presents the final results of the project, a brief synopsis of the prior tasks is presented below.

Task One

Task One consisted of the development of a survey to ascertain which welding processes and types of welding/rod were in most common usage in the US Shipbuilding and Repair Industry. Additionally, based upon the result of the survey, the types of welding rod/wire were evaluated to determine which ones would have emissions with the greatest potential health impact. Based upon the survey and the evaluation, two welding processes (Shielded Metal Arc Welding and Submerged Arc Welding), eight types of rod/wire, and nine variables (three particulate size fractions and six metals) were selected for testing.

Task Two

Task Two consisted of the development of a sampling and testing protocol. Standard EPA approved methodologies for sampling collection and sample analysis were used where applicable and appropriate for the project goals.

Task Three

Task Three consisted of the construction of the test facility from which the welding fume would be generated and the sample collected.

Task Four

Task Four consisted of the performance of the tests and the collection of the test samples, in accordance with the protocol established in Task Two.

Task Five

Task Five consisted of the chemical analysis of the samples, and the reduction of the data to allow the development of emission factors for the selected variables.

Development of Emission Factors

Emission factors were developed for the particulate size fractions and metals as sampled and analyzed in Tasks 4 and 5. The emission factors were derived using the following equation.

Equation 1: Emission Factors

$$\frac{\text{Analytical Results (lbs)}}{\text{Meter Box Reading (dscf)}} \times \text{Air Volume (cuft/min)} \times \frac{\text{Lenght of Test (min)}}{\text{Mass of Rod (lbs)}} = \text{Emission Factor}$$

where:

Analytical Results = the mass in pounds of variable measured.

Meter Box Reading = the amount of air volume in cubic feet drawn through the sampler collector.

Air Volume = the airflow in cubic feet per min through the sampling duct.

Length of Test = the amount of time in minutes the testing was conducted.

Mass of Rod = the mass of welding rod or wire consumed during the test period.

This equation results in an emission factor ("EF") for each variable, expressed in units of pounds emitted/pound welding rod consumed.

An EF was calculated based upon the result of each run of each test (three runs per test, except for tests No. 5 and 7, where two runs were completed, respectively). For the purposes of developing an EF for each specific type of welding rod/wire and its associated welding process, the calculated emission factors for all the runs in each test were averaged. The resultant emission factors are presented in the following section.

Welding Rod/Process Emission Factors

Particulate Emission Factors

Particulate emission factors were calculated for three size fractions of particulates: TSP, PM10 and PM2.5. The emission factors presented in the following Tables are given in units of pounds of particulates per 1000 pounds of rod consumed.

Table One: Particulate Emission Factors

Process/Materials		Emission Factors – lbs/1000lbs		
Welding Process	Rod/Wire Type	TSP	PM10	PM2.5
SMAW	E308-16, E308L-16	45.16	27.52	23.92
SMAW	E309-16	37.23	33.47	32.88
SMAW	E309-17, E309L-17	25.14	19.85	19.02
SMAW	E316-16, E316L-16	101.8	30.03	29.11
SAW	ER316, ER316L	7.95	7.76	7.53
SMAW	E308-17, E308L-17	26.73	27.09	26.14
SAW	ER309, ER309L	17.62	16.65	15.43
SMAW	E308-17, E308H-17	31.09	27.72	27.09

The emission factors calculated for particulate matter in this study are in general agreement with the results of other studies performed previously. These include the following observations:

1. The SAW welding process has a significantly lower fume generation rate than does SMAW.
2. The amount of rod that is converted to fume varies within a range of 1 to 10 percent.
3. In most instances, the great majority of particulates generated from the SMAW and SAW welding processes is 2.5 microns and less in size.

Table Two: Metals Emission Factors

Process/Materials		Emission Factors – lbs/1000lbs					
Welding Process	Rod/Wire Type	Cd	Cr	Pb	Mn	Ni	Cr^{+6}
SMAW	E308-16, E308L-16	0.00	0.60	0.02	0.34	0.05	0.15
SMAW	E309-16	0.00	0.74	0.01	0.36	0.06	0.09
SMAW	E309-17, E309L-17	0.00	0.68	0.01	0.44	0.05	0.08
SMAW	E316-16, E316L-16	0.00	0.83	0.01	0.42	0.08	0.19
SAW	ER316, ER316L	0.00	0.01	0.00	0.07	0.00	0.00
SMAW	E308-17, E308L-17	0.00	0.56	0.01	0.50	0.05	0.11
SAW	ER309, ER309L	0.00	0.01	0.01	0.09	0.01	0.00
SMAW	E308-17, E308H-17	0.00	1.18	0.00	0.85	0.22	0.18

With regard to metals emissions from welding, the following general observations can be made:

1. Metal emissions derived from the SAW process are significantly less than from the SMAW process. This is certainly a result of the much lower fume generation rate observed with SAW as compared to SMAW.
2. Cadmium and lead emissions are not a significant factor using these types of welding rods and their associated welding process.
3. The emission factors for manganese, total chrome and nickel had a general positive correlation with the percentage of these metals (and metal compounds) contained in the welding rod. In other words, when the concentration of the metal increased in the rod, the amount of metal emissions also increased.
4. Manganese had the highest emission factors to rod concentration ratio in comparison to the other metal tested. In other words, a greater percentage of manganese in the rod is emitted in the fume during the rod consumption than the other metals tested.

Discussion of Project Results

The development of emission factors for welding processes and the associated types of rod and wire that can be used in those processes is difficult for several reasons. Perhaps the most important is that arc welding is a multivariate process that is difficult to subject to precisely controlled testing. Uncontrolled variables in the testing procedure can result in significant variations in the measured test parameters necessary to calculate an emission factor.

The emission factors derived from this study are believed to be accurate within the established test parameters. A review of the available literature concerning emission factors for particulates and metals, including AP-42, indicate that while the emission factors for particulates are generally similar to other studies, the emission factors for metals are general lower than other published reports. As the testing, sampling and analytical protocols are not consistent between the various published studies and our study, we cannot identify any specific set of reasons why the emission factors derived from this study would be inconsistent with other research results.

The testing procedure designed for this study is believed to be representative of actual shipyard welding conditions, for these processes and materials. For this reason, the emission factors derived are believed to be an accurate representation of welding emission from shipyards.

Welding Emissions Calculator

As a deliverable of this project, a welding emission calculator was developed using an Excel spread format. The spreadsheet will provide an estimate of emissions from the welding processes and materials tested in this study. Detailed instructions for the use the emission calculator are contained in Appendix One of this report.