August 1995
NSRP 0457

SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Characterizing Shipyard Welding Emissions and Associated Control Options

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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DISCLAIMER

August 1995
NSRP 0457

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FINAL REPORT

CHARACTERIZING SHIPYARD WELDING EMISSIONS AND ASSOCIATED CONTROL OPTIONS

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In Behalf Of
SNAME SPC PANEL SP-1

FACILITIES AND ENVIRONMENTAL EFFECTS

Under the
NATIONAL SHIPBUILDING RESEARCH PROGRAM

August 1995

Task N1-92-1, Subtask 1

EXECUTIVE SUMMARY

This report was funded as an addendum sub-project under the NSRP Project entitled Air Toxics Emissions Evaluations (N-3-93). The Air Toxics Emissions Project had two primary objectives (I) identify and quantify regulated toxic air pollutants emitted from shipyard operations and (II) develop a database and analyze cost effective air toxic control strategies. This sub-project focuses on collection, filtration, and emission factors for potentially toxic welding emission.

Potentially toxic welding emissions have come under recent scrutiny with EPA regulations and regulatory agencies. With the signing of the Clean Air Act Amendments (CAAA) of 1990, shipyards face some of the most significant regulatory legislation ever enacted. Title Ill regulates hazardous air pollutants (HAPs) and poses the greatest cost and technical challenge for compliance. Title Ill requirements will be imposed equally on each air quality area. Under Title V, most shipyards will be required to obtain federally enforceable operating permits that could limit shipyard operations and increasingly regulate emissions. Therefore, it is extremely important that shipyards understand the constraints and opportunities available for welding emission reductions, collection, and filtration when addressing the CAAA of 1990.

A comprehensive analysis was performed to determine when, where, and why welding occurs in the shipyard. Then, investigations were directed at vendors and manufacturers of weld fume extraction and filtration equipment.

Determining collection equipment configurations for the shipbuilding environment is a very diffcult task because shipyards have an extremely diverse set of facilities. Each facilities and/or production area must be analyzed on a case by case basis. information presented in this report should help shipyards analyze their opportunities.

At present there is limited data available for developing standard or specific welding emission factors. Current technical reports and literature contain emission data for selected rods, electrodes and wires, under limited variations, in operating conditions. Even with limited data, emission factors have been developed for electric arc welding operations. Chapter 4 presents an introduction to current emission factors and their derivation. Research was performed and four of the most currant sources of emission factors are presented.

Environmental and occupational health and safety regulations regading welding emissions are fast becoming a concern for shipyads and their management throughout the nation. This document should serve as a source of information that presents an introduction to shipyard welding processes, available information concerning current emission factors, and options for collection and filtration of welding fumes in the shipyard production environment

DOCUMENT OVERVIEW

Chapter 1) Legislative Background

This chapter is a summary of major federal and state environmental and employee safety regulations surrounding potentially toxic welding emissions. Federal legislation involves the Clean Air Act Amendments (CAM) of 1990, and the Occupational Health and Safety Act (OSHA) indoor air quality regulations and employee toxic exposure limitations. All shipyards are governed by federal laws and regulations, which are continually increasing in rigidity with respect to exposure of employees and the general public to toxic emissions. California has some unique regulations that extend beyond federal requirements, which impose increased requirements on California shipyards for air toxics reporting, accountability, and local health risk assessments. California regulations are described briefly to provide addtional information and insight on the subject matter and illustrate possible federal trends. Many other states also have unique air quality regulations and requirements. Shipyards should consult their respective local and state regulations for specific information.

Chapter 2) Shipyard Welding Operations

Shipyard welding processes, or more specifically fusion arc welding, is performed at nearly every location in the shipyard. The process involves joining metals by bringing adjoining surfaces to extreme temperatures and fused together with a molten filler material. The types of arc welding processes used by shipyards are presented as background for greater process understanding.

Chapter 3) Fume Collection and Filtration Technologies

This chapter provides an introduction to a variety of weld fume collection and filtration technologies and equipment. The advantages and disadvantages of filtration technologies are investigated and analyzed with respect to maintenance, durability, and filtration efficiency. Weld fume colletion equipment confiturations are analyzed with respect to their applicability to the shipyard operational environment and production process areas.

Chapter 4) Current Arc Welding Emission Factor Information

Chapter 4 is presented to provide the most current information available about emission factor development and derivations. Four main sources of information are presented, which include: 1) Federal AP-42 Emission Factors, 2) SARA Guidance on welding fume emissions, 3) California Air Resources Board Position, and 4) National Steel and Shipbuilding Company (NASSCO) derived emission factors. A summary of all emission factors is provided to help explain the complexities and possible inaccuracies associated with estimating welding emissions using available emission factors.

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The National Shipbuilding Research Program (NSRP), Zachary F. Jacobs P. E., Engineering Contractor, and Dan Buell, NASSCO, would like to acknowledge the many people who gave their support and assistance throughout this project. Several individuals participated in written surveys and phone interviews, which provided much of the needed data for this study. Vendors and manufacturers of weld fume collection and filtration equipment provided information about their products and specific applications they experienced. The shipbuilding and repair industry offered information about their respective operations, facilities and state regulations concerning welding emissions. A copy of the surveys sent to the NSRP members and equipment manufacturers are supplied in **Appendix 2 and 3** respectively.

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R.M. Evans et al., *Fumes and Gasses in the Welding Environment,* American Weld Society (AWS)

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Chapter 1.

Legislative Background

1.1 Introduction

This chapter provides a summary of major federal environmental and employee safety regulations surrounding emissions of potentially toxic welding emissions. Federal legislation that potentially affect welding emissions include the Clean Air Act Amendments (CAAA) of 1990, SARA Title III, and the Occupational Health and Safety Act (OSHA) indoor air quality regulations and employee toxic exposure limitations. All shipyards are governed by federal environmental and occupation health and safety laws and regulations, which are continually increasing in rigidity with respect to exposure of employees and public to toxic emissions. California has a some unique regulations that extend beyond federal requirements that put increased requirements on California shipyards air toxic reporting, accountability and local health risk assessments. Two regulations unique to California are described briefly to provide addtional information and insight on the subject matter and illustrate possible federal trends. Many other states also have unique air quality regulations and requirements. Shipyards should consult their respective local and state regulations and regulatory agencies for specific information. With increasing environmental and health and safety regulations concerning potentially toxic welding times and particulates, controlling emissions is fast becoming a concern for shipyards and their management throughout the nation.

1.2 Clean Air Act Amendments (CAAA) of 1990

With the signing of the Clean Air Act Amendments (CAAA) of 1990, industry (shipyards in particular), now face some of the most significant regulatory legislation ever enacted. The CAAA Amendments of 1990 contain 11 new and amended titles, including enhanced non-attainment area provisions, addtional condtions for controlling hazardous air pollutants (HAPs), expanded emissions monitoring, record keeping, and increased enforcement authority. Title I, III and V are briefly discussed to provide some background.

Title I of the CAAA focuses on achieving national ambient air goals and provides for an ambitious program to reduce atmospheric ozone through a combination of measures, including substantial reductions in volatile organic compound's (VOC's). The majority of VOC's are emitted from shipyard mating processes and other surface preparation and solvent cleaning operations. Title I provisions require the development of Control Technologies Guidelines (CTG's) that industry must follow to reduce localized ozone problems. All control technologies must meet with specfic operating guidelines identified by regulatory agencies and industry. Industry will be required to use reasonably available control technology (RACT) to achieve reductions set forth in the legislation. Title 1 does have an affect on shipyard welding operations, although it displays the potential extremes that may be required to reduce or eliminate emissions.

Title III addresses toxic air emissions or Hazardous Air Pollutants (HAPs). The CAAA specifically directs the reduction of 189 of the most hazardous and pervasive air toxics through the issuance of maximum available control technology (MACT) standards for all major sources of these air toxics within 10 years. The maximum degree of reduction in emissions can be achieved through a variety of .measures, processes, methods, systems, or techniques, including design and operational changes. Table 1, presented at the end of this section, displays substances that can be present in welding electrodes and filler metals. Potential HAP emissions listed in Title III are presented as item O in the reportable list column of Table 1. Title Ill depicts that control of HAP emissions should to be phased in over the next ten years. Specific control of HAP pollutants will be a function of the amount of pollutant a facility emits on a routine basis and the control options available.

The cornerstone of the CAAA is the Title V operating permits program. The purpose of the program is to establish a central point for tracking all applicable air quality requirements and emissions for every source required to obtain an operating permit. Under Title V, all “major” sources of air pollution Will need permits to operate and a majority of shipyards will lit into this category. Although many states have previously adopted regulations tequiring a form of operating permit this is the first time that a uniform approach has been adopted throughout the nation. Now, all aspects of the CAAA will be established through one federal mechanism implemented be states. in many cases, welding processes must be addresses on the Title V permit, which could potentially impose process changes and restrictions.

1.3 California Air Toxic Issues:

1.3.1 Proposition 65 “Right to Know”

The Safe Drinking Water and Toxics Enforcement Act of 1986 (Prop. 65) was enacted by California voters, through the states voter initiative process and has three separate objectives: (1) it requires the development of a Iii of chemicals that are considered carcinogenic and/or a reproductive toxin (2) that then? be a dear and reasonable warning to exposed individuals before a business knowingly and intentionally exposes individuals to a listed chemical; and, (3) it prohibits a business from knowingly discharging or releasing a listed chemical into a source of drinking water. The previsions regarding discharges and warnings apply only to Prop. 65 “listed" chemicals and to business activities referred to as actions of “persons in the course of doing business.” Preposition 65 is “right to know’ legislation requiring California industry to notify and warn the public of exposure to carcinogens and teratogens. Shipyards potentially emit both carcinogens (hexavalent chromium, cadmium, and nickel) and a teratogen (lead).

1.3.2 AB 2588 Air Toxic Hot Spots Act of 1987

The Air Toxics Hot Spots Information and Assessment Act Assembly Bill 2588 (AB-2588) was enacted in 1987. AB-2588 was enacted in response to public concerns about the release of toxic air contaminants to the atmosphere and residential aneas near industry. Under the Act stationary sources are required to report the types and quantity of certain substances their facility routinely releases into the air. The goals of the Air Toxics Hot Spots Act are to collect emission data, identify facilities that have potential localized health and environmental impacts, ascertain the associated risks, and to notify all nearby residents of “significant” health risks. The bill has been amended to include the continuous reduction of emissions and associated significant health risks by identified facilities.

The process established by the Act requires owners and operators of facilities to prapare and submit an air toxics inventory plan, subsequent emissions inventory, and for high priority facilities, a health risk assessmentc study. The health risk assessments are reviewed and approved by the local Air Pollution Control Districts (District), the State Air Resources Board, and the Office of Environmental Health Hazard Assessment (OEHHA). Facilities that present a potentially significant health risk must notify exposed individuals and implement a plan to reduce risks below the significant level. The Air Resources Board (ARB) and the District are required to develop a program to make the emission data available to the public. Districts also publish annual reports that summarize the health risk assessment program, rank facilities according to the cancer risk posed, identify the facilities posing non-cancer health risks, and describe status on the development of control measures.

1.4 SARA Title Ill, Section 313, Toxic Release Inventory (TRI) Reporting:

In the fall of 1986, Congress passed the Emergency Planning and Community Right-to-Know Act This law, Title Ill of the Superfund Amendments and Reauthorization Act (SARA). directs states, communities and industry to work together to plan for chemical accidents, develop inventories of hazardous substances, track toxic chemical releases and provide the information to the public. SARA Title Ill is the beginning of what many consider to be "regulation by information". For the first time, the public has access to information about industrial facilities, chemical prodution and processes, including quantities. The public is also made aware of emissions and releases of chemicals to the air and water from production operations, and to the land in the from of spills.

SARA Title Ill consist of several sections that require industry to report facility specific chemical information. The sections and associated requirements and relevant chemical list are presented in the SARA table.

SARA Section	Topic	Requirement	Chemical List
301-303	Emergency Planning	LEPC Emergency Plan	Extremely Hazardous Substances
304	Emegency Notification	Accidental Release Reporting	EHSs and CERCLA (102a) Substances
311	Community Right-to-Know	MSDSs or List of Chemicals	OSHA Hazardous Chemicals
312	Communnity Right-to-Know	Inventories and Locations	OSHA Hazardous Chemicals
313	Toxic Release Reporting	Form R, Total Annual Releases	TRI Chemicals and Categories

Some of the metals present in welding electrodes and wire filler are reportable under SARA Section 313. For example, Aluminum, Copper, Chromium, and Nickel must be identified on a Form R, if they meet the threshold quantities required under Section 313 (TRI). Release estimates for these metals is briefly discussed in Chapter4.

1.5 Occupational Safety & Health Act (OSHA) Air Quality Legislation

Federal and state regulations affecting hazardous materials/wastes and toxic air emissions are the two main areas where OSHA and EPA regulations and responsibilities tend to overlap. Employees have gained rights that ensure them a safe, healthy and hazard-free work-place, while the public outside seek protection provided by EPA air quality regulations. Employee health and safety legislation drives the control of potentially toxic air emissions from welding operations in the shipbuilding environment. Occupational Safety Health Agency (OSHA) was formed to oversee the prevision of safe and healthy working conditions for both employers and employees. Operating within the Department of Labor, OSHA sets federal guidelines for, among other things, safe concentrations of various toxic substances, defining them as "threshold limit values" (TLV's). Employers are legally mandated to reduce work-place hazards, implement programs aimed at promoting job safety and good health to meet all OSHA standards. OSHA laws and regulations concerning indoor air pollution control concentrate on air contaminants inside commercial and industrial buildings. The shipbuilding industry has a wide variety of industrial buildings, ships, and work spaces where air quality must meet OSHA air quality standards to ensure a safe working environment. The laws establish threshold limit values (TLV's) and permissible exposure limits (PEL's) for over 500 regulated substances. Several of these substances are routinely found in shipyard industrial manufacturing operations that may, through either short or long term exposure, create unsafe working environments.

OSHA General Industry Safety Order (GSIO) 5150, 1536 & 1537 require the use of local exhaust hoods, if possible, for all indoor welding and cutting of stainless steel. Source capture is thought to be essential for compliance with this regulation, although this must be determined on a case-by-base basis in every shipyard. Currently, there is pending OSHA legislation, which if passed and implemented, employers may be required to achieve compliance by engineering controls or face immediate legal action. OSHA's newest Standads set employee/worker exposure limits to toxic and hazardous air contaminants as follows

(1) Time Weighted Average (TWA) Exposure Limit:

The employee's average airborne exposure in any 8-hour work shift of a 40-hour week shall not be exceeded. Measurement is quantified for particulate in milligrams (mg) of contaminant per cubic meter (m^3) of air in the worker's breathing zone.

(2) Short Term Exposure Limit (STEL):

The employee's 15-minute time weighted average exposure which shall not be exceeded at any time during a work day.

(3) **Maximum Exposure Concentration:**

The employee's exposure which shall not be exceeded during any part of the work day. If instantaneous monitoring is not feasible, then the ceiling shall be assessed as a 15-minute time weighted average.

Some of the newly-regulated substances under revised standardis include:

Contaminant	8 hr TWA (mg/m^3
Aluminum Dust (respirable taction)	**5.0**
Cement Dust (inspirable fraction)	**5.0**
Welding Fume (total particulate)	**5.0**
(Oil Mist	**5.0**
Carbon Black	3.5
Wood Dust (all soft and hard except WRC)	2.5
Copper Fume	0.1

Concerns over dean air in the industrial work-place are frequently well founded and an important issue for shipyard management and shipyard unions. Airborne contaminants (particulate dusts, fumes, mists) common to shipyard industrial settings contain potentially carcinogenic agents and contaminants that can cause reproductive harm. Many substances are currently being examined for suspected causes of cancer and a variety of other illnesses. The list of regulated substances is increasing and the exposure limits are constantly under evaluation and being reduced.

1.6 Hexavalent Chromium

When welding with electrodes containing quantities of chromium (i.e. stainless steel electrodes), the arc vaporizes some of the filler metal and the emissions will contain small quantities of hexavalent chromium (Cr^{+6}), along with a wide variety of other substances. Hexavalent chromium is a substance governed by OSHA and EPA regulations that are more stringent than those for other welding emissions due to the potential carcinogenic effects.

Hexavalent chromium is a human carcinogen and is one of the most toxic forms of metal found in commonly used industrial compounds. Many environmental and health groups are pushing to increase regulation to protect workers and the environment/public health. Currently, environmental and health groups, along with unions, are supporting a severe reduction in the PEL for Cr^{+6}. OSHA has recently denied a request for an emergency temporary standard (ETS) for Hexavalent chromium, but has vowed to draft a proposed regulation by early 1996. OSHA is compiling feasibility and health assessments for rule-making. They have also spoken with industrual organizations such as the Chrome coalition and have drafted a list outlining the demands for the rule-making.

Many variables drive the development of hexavalent chromium and other potentially toxic particulate within the welding environment The size of the work piece, weld time, amperage, hours of operafion, type of shielding, and several other factors affect the generation of Cr_{+6}. Hexavalent chromium and other potentially toxic emissions will be discussed in more detail in Chapter 4.

1.7 List-of-lists and Summary:

Welding rods, electrodes, and wires contain many substances that are regulated by EPA and OSHA laws. Table 1 itemizes the majority of substances that are potentially present in shipbuilding electrodes. The last column in Table 1 presents a letter that corresponds to the regulation that each substance is regulated. Table 2 is the regulatory list referred to in the last column of table 1. The list of regulations contains the following: 5 Federal EPA regulations, 3 Occupational Health regulations, 3 California EPA air quality regulations, and 5 miscellaneous state and federal regulations. All of the constituents within the weld rod (Table 1) have the potential to become an airborne emission.

1.8 Summary:

In summary, increasing environmental and occupational health regulations concerning welding fumes and particulate is a concern for shipyard management throughout the nation. Strict environmental legislation in the form of the 1990 Clean Air Act Amendments Title V permiting and Title Ill Hazardous Air Pollutants (HAP's) will require that emissions from welding and cutting operations be addressed. As regulations become more stringent and structured, air quality districts will have increased power to regulate the way industry normally conducts business. Similarly, OSHA regulations are becoming more stringent with respect to indoor air quality and employee toxic exposure.

Table 1-1 Reportable/Regulated Components of Welding Electrodes, Rods, & Wire

Components	CAS #	List-of-lists Regulation (See Table 2)
Aluminum (Al)	7429-90-5	C, D, F, G, M, N,
Cadmium (Cd)	7440-43-9	A, B, C, D, G, I, M,
Carbon (C)	7440-44-0	none
Chromium (Cr)	7440-47-3 (HEX) 18540-29-9	B, C, D, F, G, I, M, N, O
Cobalt (Co)	1307-96-6	K, O
Columbium (Cl)		NONE
Copper (Cu)	7440-50-8	B, C, D, F, G, M, N, P,
Iron (Fe)	7439-89-6 Oxide 1309-37-1	C, N, M, N,
Lead (Pb)	7439-92-1	B, C, D, F, G, I, K, N, O
Magnesium (Mg)	7440-22-4 Oxide 1309-48-4	C, N, P,
Manganese (Mn)	7439-96-5	C, D, G, M, N, I, O
Molybdenum (Mo)	7439-98-7	M, N,
Nickel (Ni)	7440-02-0	B, D, G, K, M, N, O
Phosphorus (P)	7723-14-0	D, E, G, I, J, M, N, O, P,
Silicon (Si)	7440-21-3	M
Silver (Ag)	7439-95-4	B, C, D, F, G, M, N, P,
Sulfur (S)	7704-34-9	N, P
Titanium (Ti)		NONE
Vanadium (V)	7440-62-2	D, G, N
Zinc (Zn)	7440-66-6	B, C, D, F, G, N,

Table 1-2. Regulatory List-of Lists

A: **CALIFORNIA OSHA CARCINOGEN USER REGISTER CHEMICALS**
Ref: California Occupation Safety and Health Dept.
Date of List May 1993

B: **EPA LIST OF PRIORITY POLLUTANTS**
Ref: Environmental Protection Agency
Date of List Dec. 1992

C: **AB 1803 - WELL MONITORING CHEMICALS**
Ref: California Department of Health Services
Date of List Sept. 1992

D: **SARA SECTION 313 TOXIC CHEMICALS**
Ref: EPA Emergency Planning and Community Right-to-Know Act, Section 313
Date of List Jan 1992

E: **SARA SECTION 302 EXTREMELY HAZARDOUS SUBSTANCES**
Ref: EPA Emergency Planning and Community Right-to-Know Act, Section 302
Date of List Jan 1992

F: **MCL (MAXIMUM CONTAMINANTS LEVELS) LIST OF CONTAMINANTS**
Ref: California Department of Health Services
Date of List Oct. 1990

G: **AB 2588 - AIR TOXICS "HOT SPOTS" CHEMICALS**
Ref: California Air Resources Board
Date of List June 1993

H: **DHS DRINKING WATER ACTION LEVELS**
Ref: California Department of Health Services
Date of List Oct. 1990

I: **AB 1807 - TOXIC AIR CONTAMINANTS**
Ref: California Air Resources Board
Date of List Mar 1991

J: **NESHAP (NATIONAL EMISSION STANDARD FOR HAZARDOUS AIR POLLUTANTS)**
Ref: EPA Office of Air Quality Planning and Standards
Date of List Apr. 1991

K: **PROPOSITION 65 CHEMICALS**
Ref: Office of Environmental Health Hazard Assessment
Date of List Apr. 1993

L: **DOT INHALATION HAZARD CHEMICALS**
Ref: Department of Transportation
Date of List Mar 1993

M: **PERMISSIBLE EXPOSURE LIMITS FOR CHEMICAL CONTAMINANTS**
Ref: Department of Industrial Relations
Date of List Feb. 1992

N: **HAZARDOUS SUBSTANCES LIST (AKA "THE DIRECTOR'S LIST)**
Ref: Department of Industrial Relations (CAL/OSHA)
Date of List May 1992

O: **HAZARDOUS AIR POLLUTANTS (HAP's)**
Ref: US EPA

P: **ACTIVELY REGISTERED PESTICIDES IN CALIFORNIA**
Ref: Department of Pesticide Regulation
Date of List July 1993

Chapter 2.

Shipyard Welding Operations

2.1 Introduction to Shipbuilding Materials

The structural frame-wok of most ships is constructed of various grades of mild and high strength steel. Steel provides the formability, machineablity, and weldability required, combined with the strength needed for ocean going vessels. Various grades of steel predominate most ships, although aluminum and other nonferrous materials are used for some superstructures (deck-houses) and other specific areas within the ship. Other materials found on ships, like stainless steel, galvanized steel, and copper nickel alloy, are used for a variety of corrosion resistant purposes and strutural integrity. Although, nonferrous materials are used in far less quantity than steel. Shipboard systems (i.e. ventilation, combat, navigational, piping, etc.) are usually where the more “exotic” materials are used. These materials are required to perform a wide variety of functions including the ship propulsion systems, backup power, kitchens, pump stations for fuel transfer and combat systems.

Steel used for constriction can be subdivided into three types: mild, high-strength, and high alloy steel. Mild steels, have valuable properties and are easy to produce, purchase, form, and weld. On the other hand, high-strength steels are mildly alloyed to provide mechanical properties that are superior to the mild steels. Extremely high-strength steels have been developed specificaliy for use in naval construction. in general, the high strength and high yield steels are called HY-80, HY-100, and HY-130. They have strength properties in excess of the commercial grade high strength steels. Welding processes are more complicated for highstrength steels in order to prevent deterioration of their properties. Specific weld rods are needed for high-strength steel and weld joint heating (preheating) is usually required. A third general class of steels, the high-alloy steels, are made by including relatively large amounts of alloying elements, such as nickel, chromium, and manganese. These steels, which include stainless steels, have valuable conusion resistance properties and also require special welding processes.

Steel is an excellent material for shipbuilding purposes and the choice of welding electrode is critical in all welding applications during construction. The standard goal is to obtain a weld with equivalent strength charactenstics to the base metal. Since minor flaws are likely to occur in production welding, welds are often designed and welding electrodes chosen to produce welds with properties in excess of those of the base metal.

Aluminum has found increased application as a shipbuilding metal due to its high strength-to-weight ratio compared to steel. Although the use of aluminum for hulls has been limited, aluminum superstructures are becoming more common for both naval and merchant ship construction. Vessels solely made from aluminum are primarily smaller size boats, such as fish boats, pleasure boats, small passenger boats, gunboats, and hydrofoils. The aluminum used for shipbuilding and repair is generally alloyed with manganese, magnesium, silicon, anti/or zinc. These alloys offer good strength, corrosion resistance, and weldability.

2.2 Common Welding Processes

Shipyard welding processes, or more specifically fusion welding, is performed at nearly every location in the shipyard environment. The process invoives joining metals by bringing adjoining surfaces to extremely high temperatures to be thsed together with a molten filler material. A heat source is used to heat the edges of the joint permitting them to fuse with molten weld filler metal (electrode, Wire or rod). The required heat is usually generated by an electric arc or a gas flame. Shipyards choose the type of welding process based on customer specifications, prodution rates, and a variety of operating constraints. For commercial shipbuilding, welding processes are subject to review and approval by the regulatory bodies of the United States Coast Guard (USCG) and/or the classification societies of the American Bureau of Shipping (ABS). In U.S. practice, most oversight and inspection is petiormed by the ABS, operating under a memorandum of understanding with the USCG. The ABS Rules for Building and Classing steel vessels contains a section on the required procedures and practices of welding for hull construction and outfitting. Similar standards and requirements have been establish by the U.S. Navy for naval ship construction, repair, and modification. Standards for military vessels are usually more stringent than commercial vessels.

An important factor with respect to the fusion welding processes is arc shielding to protect the weld pool. The temperature of the weld pool is substantially higher than the adjoining metals melting point. At extremely high temperatures, a reaction with oxygen and nitrogen in the atmosphere is rapid and has negative affects on the weld strength. Should oxygen and nitrogen from the atmosphere become trapped within the weld metal and molten rod, embrittlement of the weld area willl occur. To protect against this weld impurity and ensure weld quality, shielding from the atmosphere is required. In most welding processes, shielding is accomplished by addtion of a flux a gas, or a combination of the two. Where a flux material is used, gases generated by vaporization and chemical reaction at the electrode tip, result in a commbination of flux and gas shielding that protect the weld from nitrogen and oxygen entrapment. Shielding will be discussed in the following sections as specific welding precesses are described.

In electric arc welding, a circuit is created between the work-piece and an electrode or wire. When the electrode or wire is held a short distance away from the work piece, a high-temperature are is created. This arc generates sufficient heat to melt the edges of the work piece and the tip of the electrode or wire to produce a fusion welding system. There are a number of electric arc welding processes suitable for use in shipbuilding. All processes require shielding of the weld area from the atmosphere. They may be subdivided into flux-shielded and gas-shielded processes.

Manufactures of welding equipment and associated consumable and non-consumable products report that arc welding with consumable electrodes is the most universal welding processes. The percentage of consumable electrodes purchased by all weld rod users in 1991 were distributed as follows:

Table 2.1 Welding Industry Purchase Breakdown in 1991

Welding Process	%
Shielded Metal Arc Welding (SMAW)	45
Gas Metal Arc Welding (GMAW)	34
Flux Core Arc Welding (FCAW)	17
Submerged Metal Arc (SAW)	4

Table 2.2 National Steel and Shipbuilding 1991 Breakdown

Welding Process	%
Shielded Metal Arc Welding (SMAW)	47
Gas Metal Arc Welding (GMAW)	8
flux Core Arc Welding (FCAW)	40
Submerged Metal Arc (SAW)	5

It is expected that this proportionality is shipyard and construction project specific.

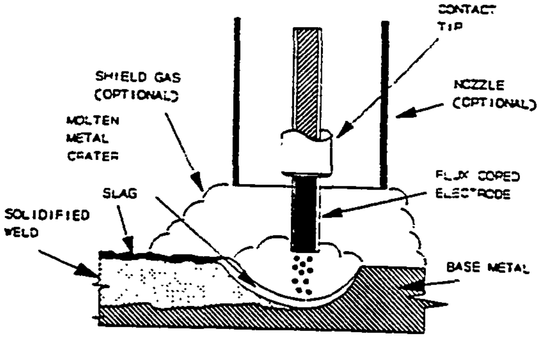
2.2.1 Shielded Metal Arc Welding (SMAW)

Flux-shielded electric arc welding processes are distinguished primarily by their manual or semi-automatic nature and the type of consumable electrode used. The SMAW process utilizes a consumable electrode (12 to 18" in length) with a dry flux coating, held in a holder and fed to the work piece by the welder. The electrode consists of the solid metal filler rod core, made from either drawn or cast material covered with a sheath of metal powders. SMAW is also frequently refereed to as "Stick Welding" and "ARC Welding". The electrode metal is surrounded by flux that melts as welding progresses, covering the deposited molten metal with slag and enveloping the immediate area in an atmosphere of protective gas. Numerous electrodes are available, as classified by the American Welding Society (AWS). The choice of eleotrode is base on the ABS or Miliitry Specification that are based on the required composition and properties of the deposited weld metal and strength requirements of the structure.

Table 2.3 Advantages and Disadvantages of SMAW Welding Processes

Advantages SMAW	Disadvantages SMAW
Able to weld thick sections	Higher potential for weld contamination
All position capability good arc visibility	Interrupted welding due to fixed length electrodes
Simple, low cost, low maintenance, equipment	Process leaves slag that must be removed before next layer is deposited
Good accessibility in space restricted areas	Poor for aluminum and most bronzes

Figure 2-1 Diagram of SMAW Welding Process



Manual SMAW may be used for downhand (Flat), horizontal, vertkal, and overhead welding. SMAW processes may also be used semi-automatically through the use of a gravity welding machine. Gravity machines use the weight of the electrode and holder to produce travel along the work piece.

2.2.2 Submerged Arc Welding (SAW)

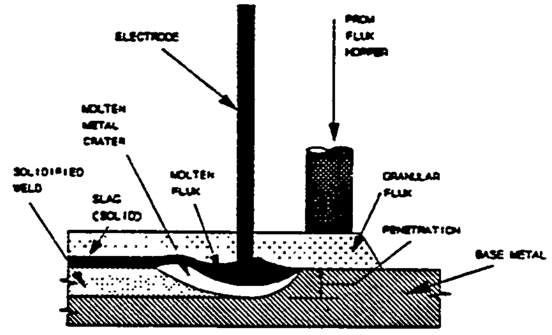
Submerged arc welding (SAW) is another flux-shielded electric arc welding process used in many shipyards. in this process, a blanket of granulated flux is deposited on the work piece, followed by a consumable bare metal wire electrode. Generally, the electrode serves as the filler material, although is some cases metal granules are added to the flux. The are, submerged in the blanket of flux, melts the flux to produce a protective insulated molten shield in the weld zone. High heat concentration permits heavy weld deposits at relatively high speeds. After welding, the molten metal is protected by a layer of fused flux which is subsequently removed and may be recovered.

Table 2.4 Advantages and Disadvantages of SAW Welding Processes

Advantages SAW	Disadvantages SAW
Excellent weld quality	Welding positions limited to flat horizontal
No flash bums	Ferrous metals and high nickel alloys
Less angular weld distortion	Best for long welds on thick sections
less weld join preparation	slag and unused flux must be removed
	Joint fit-up and design is critical

Submerged arc welding must be performed downhand and is ideally suited to butt welding plates together on panel lines, platen areas, and erection areas. The SAW process is generally fully automatic and mounted on a moving carnage or self propelled platform on top of the work-piece. Since the SAW process is primarily automatic, a good portion of time is spent aligning the weld joint with the machine. Similarly, the SAW arc operates under a covering of granulated flux, the fume generation rated (FGR) or fume formation rate (FFR) are low and will remain constant under various operating conditions provided that there is adequate flux cover.

Figure 2-2 Diagram of SAW Welding Process



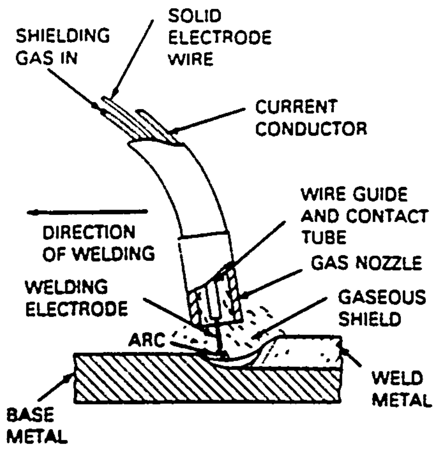
2.2.3 Gas Metal Arc Welding (GMAW)

A second major category of electric arc welding are the gas shielded processes. These processes generally use bare were electrodes with an externally supplied inert active, or a combination of inert and active shielding gases. The first type of welding process is called gas metal arc welding (GMAW) or it is commonly referred to as metal inert gas (MIG) welding. GMAW uses a consumable automatically fed small diameter Wire electrode and gas shielding. GMAW is the answer to a long-sought method of being able to weld continuously without the interruption of changing electrodes, which necessitated an automatic wire feeder. A wire spooling system provides the electrode/wire filler rate that is at a constant speed or the speed fluctuates with a voltage sensor. At the point where the electrode meets the weld arc, an argon or helium being used as the shielding gas is supplied by the welding gun. It was found that for welding steel, a combination of CO_2 and/or an inert gas could be used. Often, a combination of the gases is used to optimize cost and weld quality.

Table 2.5 Advantages and Disadvantages of GMAW Welding Processes

Advantages GMAW	Disadvantages GMAW
No slag removal & minimal interpass cleaning	Handling gas bottles for field work is expensive
High quality for various sized plates	Complicated and expensive equipment
Good positioning welding abilities	Limited tight position welding

Figure 2-3 Diagram of GMAW Welding Process



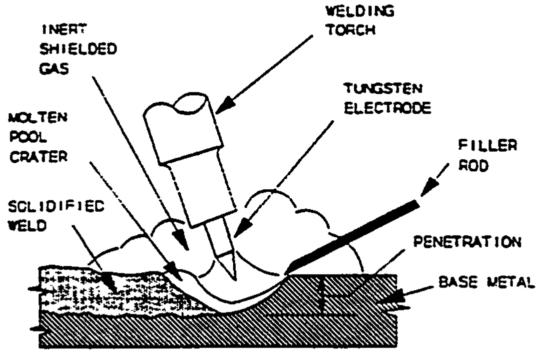
2.2.4 Gas Tungsten Arc Welding

Another type of gas shielded welding process is the gas tungsten arc welding (GTAW) or sometimes referred to as tungsten inert gas (TIG) welding, or the trade name Heliarc because helium was initially used as the shilding gas. This was the first of-the "new" welding processes, following stick arc by about 25 years. The arc is generated between the work piece and a tungsten electrode, which is not consumed. An inert gas, usually argon or helium, provides the shielding and provides for a dean low fume process. Also the TIG welding process arc does not transfer the filler metal, but simply melts the material and the wire, resulting in a cleaner weld. TIG welding is most often employed in shipyard for welding aluminum, sheet metal, small diameter pipes and tubes, or to deposit the first pass on a multi-pass weld in larger pipe and fittings.

Table 2.6 Advantages and Disadvantages of GTAW Welding Processes

Advantages GTAW	Disadvantages GTAW
Excellent quality and precise filler metal placement	Both hand must be used to hold filler wire
Minimal stub loss either manual or automatic	Shielding gas can be disturbed by gusts of wind
No slag removal & minimal interpass cleaning	Limited application in outdoor environments
All position welding abilities	Slow production rates

Figure 2-4 Diagram of GTAW Welding Process



2.2.5 Flux Core Arc Welding (FCAW)

Flux cored arc welding uses equipment similar to GMAW in that the Wire is fed continuously to the arc. The main differances is that the FCAW electrode is a tubular electrode wire with a flux core center that helps with localized shielding in the welding environment. Some flux cored wire provide adequate shielding with the flux core alone. However, many FCAW processes used in the shipbuilding environment require the addition of gas shielding for the quality requirements of the shipbuilding industry (i.e. ABS and the NAVY).

Table 2.7 Advantages and Disadvantages of FCAW Welding Processes

Advantages FCAW	Disadvantages FCAW
Large single pass fillets possible	Weld spatter can clog gas nozzles
Tolerant of mill scale	Slag coating must be removed
All position welding with excellent productivity	Bulky equipment causes accessibility problems
Less joint prep. than for SMAW & GTAW	Equipment is expensive

The FCAW process provides a high quality weld with increased production rates and welder efficiency over the traditional SMAW process. The FCAW process allows for a full range of versatility with production requirements such as overhead and vertical welding. FCAW electrodes tend to be a little more expensive then SMAW materials although, in many cases, increased quality and productivity are worth the investment.

Figure 2-5 Diagram of Flux Core Wire

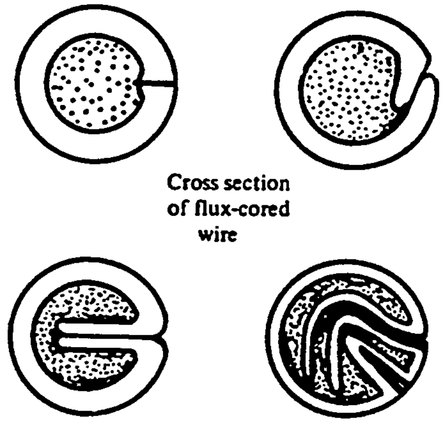
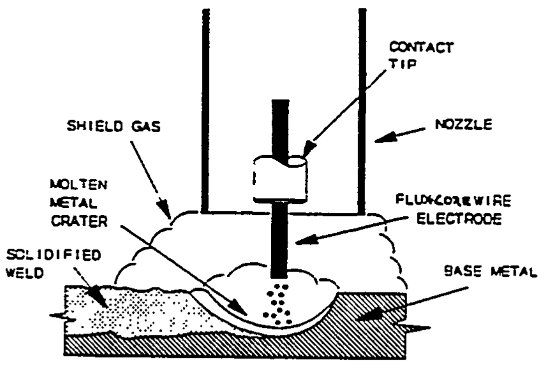


Figure 2-6 Diagram of FCAW Welding



2.2.6 Plasma-Arc Welding (PAW)

The last of the shielded gas welding processes is plasma metal inert gas welding (PAW). PAW is very similar to the GTAW process except that the arc is forced to pass through a restriction before reaching the work-piece. The result is a jet stream of intensely hot and fast moving plasma. The plasma is an ionized stream of gas that carries the arc, which is generated by constricting the arc to pass through a small orfiice in the torch. Plasma metal inert gas welding results in a more concentrated, high-temperature arc and thus permits faster welding. Aside from the use of the orifice to accelerate the gas, plasma metal inert gas welding is identical to TIG welding, using a non-consumable tungsten electrode and an inert gas shield as displayed in figure 2-7.

Figure 2-7 Diagram of Plasma Arc Process

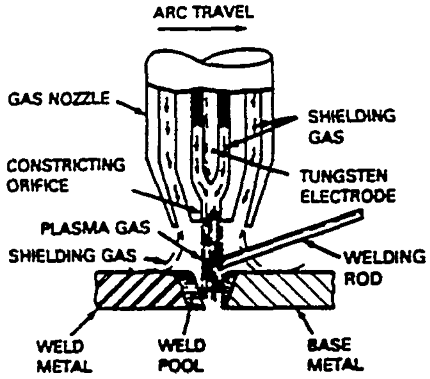


Table 2.8 Welding Process Comparison Matrix	SMAW	GTAW	GMAW	PAW	FCAW	SAW
Deposition Rate	Fair	Poor	Good	Good	Good	Excellent
Field Work	**Excellent**	Poor	Fair	Poor	Excellent	Fair
Equipment Maintenance	Low	Low	Medium	Medium	Medium	Medium
Smoke/Fume Generation	High	Low	Medium	Low	High	Very Low
Variety of Metals Weldability	Sat	Excellent	Good	Good	Good	Fair

Plasma-arc welding is generally manual and has minimal use in shipbuilding although it is sometimes used for flame spraying applications. Plasma arc is used primarity for steel cutting in the shipbuilding environment Table 2.8 provides a comparison of the major welding processes. Each process has its own set of applications due to the constrmints offered by the process.

2.2.7 Gas Welding, Brazing and Soldering

Gas welding employs heat generated by the burning of a gas fuel and generally uses a filler rod for the metal deposited. The most common fuel is acetylene, used in combination with oxygen (oxyacetylene gas welding). A hand [redacted] filler material used to fill gaps or grooves. The molten metal, mainly filler metal, solidifies as the torch progresses along the work piece. Gas welding is comparatively slow and not suitable for use with automatic or semiautomatic equipment. Consequently, it is rarely used for normal production welding in shipyards. The equipment is small and portable and it can be useful for welding thin plate (up to about 1/4-inch, or 7 mm), as well as for small-diameter pipe, HVAC trunks (sheet metal), electrical cableways, and for brazing or soldering. Identical or similar equipment is used for cutting as will be described in a further section.

Soldering and brazing are techniques for bonding two metal surfaces without melting the parent metal. A liquid is made to flow into and fill the space between the two surfaces then solidfy. If the temperature of the filler metal is below 450 C, the process is called soldering and if it is above 450 C, the process is called brazing. Soldering is commonly done using soldering iron, by flame heating, resistance heating, or induction heating. On the other hand, brazing includes the use of flame heating, resistance heating, and induction heating. Brazing may also be done by dipping parts in a bath. Soldered and brazed products joints do not have strength properties that are equivalent to welded joints. Consequently, brazing and soldering find limited application to shipbuilding and repair except for primarily small diameter pipe joints, sheet metal fabrication, small infrequent joiner work and maintenance functions.

2.2.8 Other Welding Processes

There are additional types of welding that may be used in the shipyard environment in small quantities for a varity of reasons. These are electroslag, electroslas, thermite, laser, electron beam and stud welding. Eleotroslag welding transfers heat through molten slag, which melts the work piece and the filler metal. Although the equipment used is similar to that used for electric arc welding, the slag is maintained in a molten state by its resistance to current passing between the electrode and the work piece. Therefore, it is a form of eleotric resistance welding. Often, a cooled backing plate is used behind the work piece to contain the molten pool. Another process, electrogas welding, employs a similar setup but uses a flux coated electrode and CO_2 gas shielding. Both of these processes are very efficient for automatically making vertical butt welds and are highly advantageous for thicker plate. These techniques are expected to receive considerably wider application in shipbuilding.

Thennite welding is a process that uses superheated liquid metal to melt the work piece and provided filler metal. The liquid metal results from a chemical reaction between a melt oxide and aluminum. The liquid metal is poured into the cavity to be welded and the cavity is surrounded by a sand mold. Thermite welding is somewhat similar to casting and is primariiy used to repair castings, forgings or to weld large structural sections such as a stem frame.

Laser welding is a new technology which uses a laser beam to melt and join the work piece. Although the feasibility of laser welding has been proven, cost has prevented its commercial application to date. The potential for efficient high quality welding may make laser welding an important technique for shipbuilders in the future.

Another relatively new welding technique is called electron beam welding. The weld is made by firing a stream of electrons through an orifice to the work piece, which is surrounded by an inert gas. Electron beam welding does not depend on thermal conductivity of the material to melt the metal. Consequently, both lower energy requirements and reduced metallurgical effects on the steel are significant benefits of this technique. As with laser welding, high cost is a major problem.

Stud welding is a form of electric arc welding in which the stud itself is the electrode. A stud welding gun holds the stud while the arc is formed and the plate and stud end become molten. The gun then forces the stud against the plate and the stud is welded to the plate. Shielding is obtained by the use of a ceramic firrule surrounding the stud. Stud welding is a semi-automatic process commonly used in shipbuilding to faciliite installation of non-metallic materials, such as insulation to steel surfaces.

Chapter 3.

Weld Fume Collection
and
Filtration Technologies

3.1 Introduction

This section of the report provides an introduction to the variety of weld fume collection and filtration technologies and commercially available equipment. The advantages and disadvantages of mechanical and electrostatic filtration technologies are investigated and analyzed with respect to maintenance, durability, and filtration efficiency. Weld fume collection equipment configurations are analyzed with respect to their applicability to the shipyard operational environment and production process areas. Appendix 1 provides the results of investigations and research about shipbuilding processes and facilities. The investigations serve as the basis for determining collection variations that could be applied in the shipyard Developing generic collection configurations for the shipbuilding environment is a very diffcult task and them is no single configuration that can be applied throughout the shipyard. Shipyards have an extremely diverse set of facilities and production constraints. Each Shipyard facility, area, and production process must be handled on a case by case basis when addressing weld fume collection and filtration.

3.2 Current Filtration Technology Emissions Equipment

One solution for reducing welding emission releases from shipyards is through the use of collection and filtration equipment Fumes created during welding operations generally contain particulate in the sub-micronic range (i.e. 0.01 -1.0 microns in diameter) and the PM-10 range (<10 microns), which requires specialiied filtration equipment. A micron is on millionth of a meter.

There are essentially two major categories of filtration technology that can be applied to sub-micronic weld fume/dust particulate emissions. The first is electrostatic precipitation (ESP) and the second involves a variety of mechanical media filters. A discussion of welding emission particles and filtration efficiency rating is presented prior to a more indepth presentation about mechanical and electrostatic precipitation filtration technologies.

Airborne “particles” can be in the form of smoke, weld fumes, mist fumes, dust aerosols and vapors. Separation of particulate from the industrial airstream is referred to as filtration. Particles can be very small and are generally only visible when they are present in dense concentrations such as experienced near the are of welding operations. It is diffcult to tell if small particles present in high concentrations are suspended in air (as particles) or diffused throughout as gas or vapor. Although, the majority of welding metal emissions of environmental concern are treated as particulates. The lower size boundary where particulate act as true particles is about 0.01 microns. Normal methods of collection, separation, and filtration do not generally apply to particles smaller than 0.01 microns and removing them from industrial process air requires technologies used for gaseous materials, which will not be discussed in this report. Particulate above 0.01 microns are considered to be filterable and can be addressed with electric and mechanical cleaners.

3.2.1 Efficiency Rating Systems

Efficiency rating systems need to be understood with respect to air filtration efficiency and co!lection efficiency. Filtration efficiency is a function of how well the filter performs air cleaning and particle removal, while collection efficency refers to the percentage of the smoke/fumes generated by the arc that are captured by the system and directed through the filter.

Collection efficiency is easy to understand. if a welding hood and ducting system is located directly above an emission source, 100% collection efficiency can be achieved. For example, if there is no place for the fumes to escape, 100% collection is achieved. Extremely high collection efficiencies are diffilcult to achieve and in many cases, collection efficiency WiIl be a function of how diligent welders are at ensuring that the collection hood is placed over the welding arc.

Filtration efficiency, on the other hand, is a more confusing concept to comprehend and to specify. Filters are designed for efficiencies for various sized particles. For example, some media filters are 98% efficient at filtering particles down to 0.3 microns, while other fitters may be 90% efficient at filtering particlas down to 0.01 microns. Therefore, filtration effciency is dependent on the particulate size specified and particle size must be taken into account when specifying efficiency needs. it is also important to note that sometimes filtration efficiency will be reduced as the filter becomes filled with Particles.

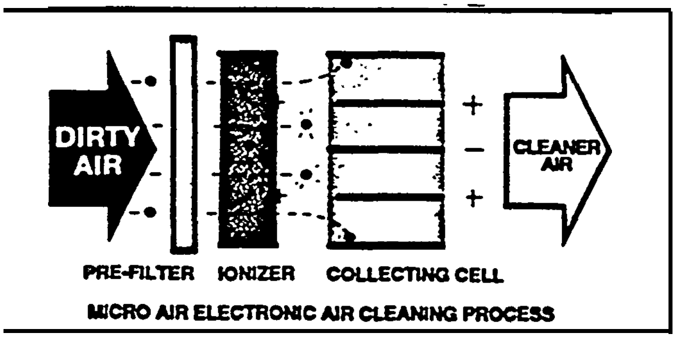
3.2.2 Electrostatoc Precipitators (ESP)

Electrostatic preapitators (ESP) or sometimes called electronic air cleaners are frequently used to filter air pollutants in the range of 10 microns or smaller. To understand the theory of electrotatic precipitation and pariticle attraction, think of static electricity and a positively charged common hair comb attracting small bits of paper. The example illustrates the attracting force employed in electronic air cleaners and the particulate that passes though. Under normal condtions, particles in the air tend to be neutrally changad. An electronic air cleaner alters the electrical balance of particles in the air by providing a high positive charge that causes the particles to attract to a collector plate as displayed in figure 3.1.

High efficiency two-stage electrostatic precipitators are generally designed to filter and collect particles down to 0.01 microns, such as those associated with industrial oily smokes and metal fumes from welding operations. A two stage electronic precipitator is composed of two sections; a charging section (ionizer) and a collection plate section as displayed in figure 3.1. The first section contains a series of Was suspended between metal plates that chage the particles as they pass through. The collecting section consists of a series of parallel flat metal plates, spaced spat with alternate plates that are charged and grounded. Particles are driven by a repelling force from the charged plates toward the ground plates to which particles will be collected. The exact configuration of the ESP system will vary from one company to another, but the basic operation is based on the same principals.

Many electronic air cleaner systems contain some type of mechanical pre-filter. Heavy-duty, reusable, mechanical filters serve to aid in the air distribution across the face of the

Figure 3-1 Electronic Precipitator Flow Diagram *(Micro Air)*



electrostatic units and to remove large particles. Pre-filtration and associated capturing of large particles extends the operational life of the electrostatic portion of the filter. Without a pre-filter, electrostatic precipitators can become overloaded with larger contaminants and arc the precipitator, causing severe reductions in filtration efficiency.

As particles buildup on the plates, filtration effciency drops and the plates become saturated with particles. Particle buildup causes the ESP system to need cleaning and continuous maintenance. Most ESP filtration systems require a manual cleaning and maintenance progrom. The type of cleaning method employed will be largely a function of the contaminants collected and individual prefmnce. There are four basic methods of manual ESP maintenance cleaning: 1) hot detergent bath, 2) cold soak 3) high pressure spray, and 4) automatic parts washer cleaning. Hot detergent bath cleaning is the most widely recommended method and with the proper detergent selection, will quickly remove most welding emission contaminants collected in the precipitator. The cold soak method is more time consuming and is less effective on tough contaminants. High pressure spraying is a highly effective method of cleaning, especially if warm water and detergent is used. Care must be taken to ensure that all plates and components as well as insulator surfaces are cleaned. Automatic parts washers may be designed to perform the cleaning as necessary.

Automatic cleaning systems are provided by some manufactures of electrostatic Precipitators, although this does not eliminate the need to perform manual maintenance cleaning. Most manufacturers of ESP equipment provide maintenance cleaning services and/or programs. Also, all wastewater associated with the ESP cleaning process must be disposed of properly within the guidelines of local, state, and federal regulations.

3.2.3 Mechanical Filtration Devices

Mechanical filtration systems serve as an excellent method for filtration of welding emissions. Many mechanical filters use pleated paper or polyester filter cartridges to dean or filter air that flows through. In many cases, standad mechanical filtration systems are the preferred choice to dean a wide variety of industrial, as well as, residential dusts in the range of 1 micron and larger. Also, in recent years, high efficiency mechanical media filters are becoming very popular for smaller particle sizes and in some cases, are highly efficient down to 0.01 microns in aerodynamic diameter.

The approach to pre-filtration as discussed in the ESP section is also primarily used when applying mechanical filters to industrial air streams that require removal of very small particles. Pre-filtration stages are generally used to provide a systematic reduction in the size of particles being filtered.

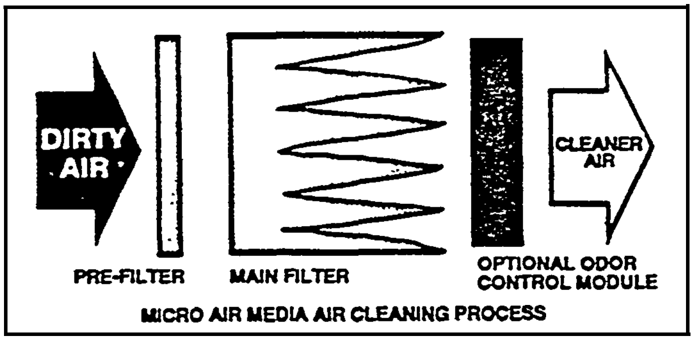
Mechanical filters are designed primarily for “dry” industrial dusts and smokes, but some pre-filters tolerate a minimal amount of moisture in the air. Excess fluids of any type in the air stream can lead to failure of mechanical fitters due to the plugging of the fitter media. Excess moisture will lead to a reduction in collection flow-rate, which leads to a reduction in fitter life. Pre-filters can be used to collect the majority of moisture and larger particles developed in welding operations.

Most mechanical media filters are disposable, although, some media filters can be cleaned and recyded 2 or 3 times by outside services prior to disposal. The cost of the mechanical fitter insert and the cost of cleaning will drive the need to replace the unit or have it cleaned. Similarly, the cast of mechanical filters is generally a function of their efficiency, particle size being filtered and the overall size of the unit. Figure 3.2 provides an illustration of a generic-mechanical filtration system.

3.2.3.1 Media Bag Filters

Media bag filters are frequently used in dust collectom and are a tubular bag or cube design as displayed in figure 3-3. These filtration devices are highly effcient for collecting fibrous and other large size process particulate at relatively high concentration levels and flow rates. Although they generally will have little application to weld fume filtration, bag filters could be used as a pre-filter in larger volume applications.

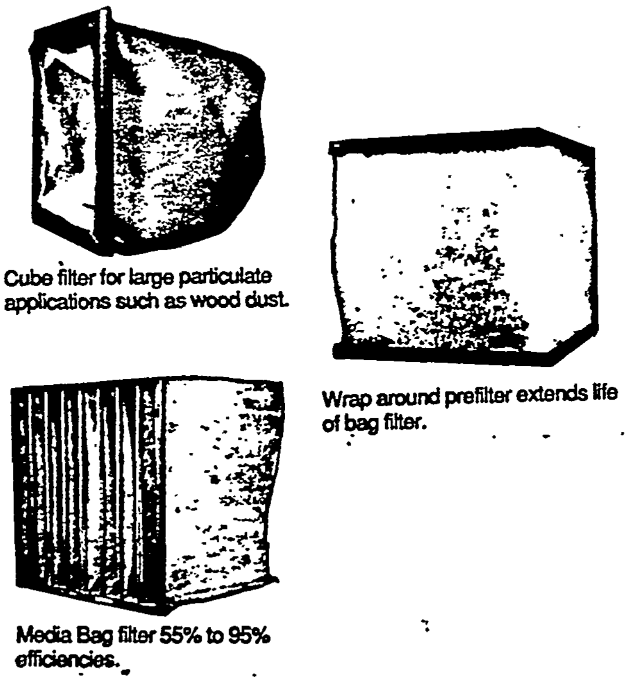
Figure 3-2 Mechanical Filtration Systems (*Micro Air*)



3.2.3.2 Cartidge Filters

Cartridge filter elements are generally cylindrical in shape and are very popular far applications involving weld fume filtration and dust collection. The cartridge fitter elements are frequently cleaned on-line with a reverse pulse of air Pressure during the dust collection process. This cleaning feature maintains a relatively constant pressure drop across the filter media, allowing a constant flow-rate for particulate capture. Some cartridge units offer high filtration efficiency and are capable of trapping up to 99% of sub-mioronic (0.01 to 1 micron) materials and virtually 100% of larger dust partiicles (1 to 100 miorons or larger). Cartridge filters are sometimes used as a pre-fitter to a high efficiency filter or are of high enough efficiency to serve as a final filter. Exact efficiency of the filtration systems are not standardized and will vary from manufacturer to manufacturer. Many systems that employ cartridge filtration are sized at the factory for specific system applications.

Figure 3-3 Media Bag, Cube and Pre-Filters

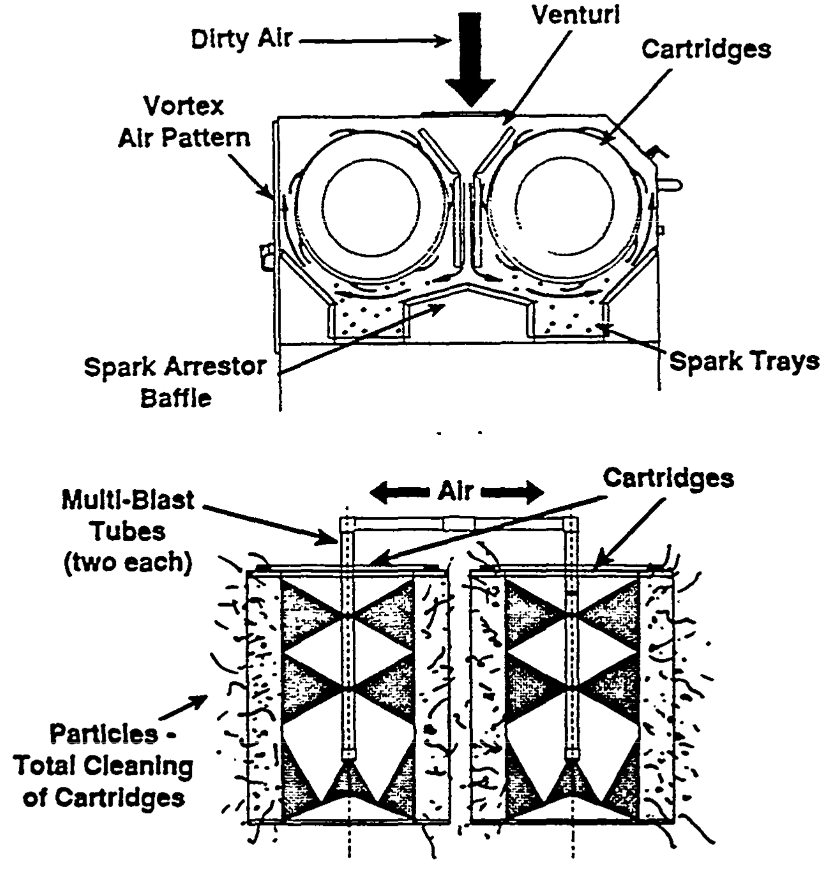


Cube filter for large particulate applications such as wood dust.

Wrap around prefilter extends life of bag filter.

Media Bag filter 55% to 95% efficiencies.

Figure 3-4 Cartridge Filters and Reverse Pulse Cleaning



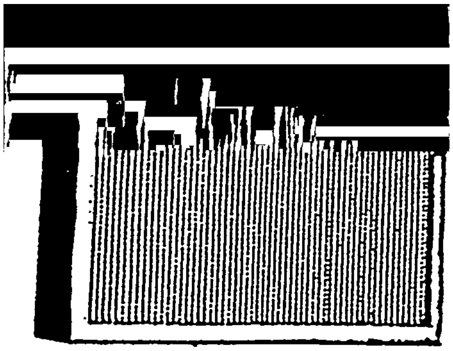
3.2.3.3 High Efficiency V-Bank Media Filters

V-Bank or V-Bag filters are highly efficient bag-type filters designed for smaller particle sizes. They are more efficient than standard bag fitters but generally less efilcient than EPS or high efficiency mechanical media filter systems. V-bag filters can exhibit efficiancies of around 95% at 0.3 microns depending on the manufactrer. V-bag filters are disposable and can be used in conjunction with a lower efficiency pre-filter to prolong its life and as a pre-filter to a higher efficiency filter. For clean-room and very small particle tiltering needs, a HEPA filter or EPS system should follow the high efficiency V-bank

3.2.3.4 HEPA filters 99.97 % Efficient

HEPA otherwise known as High Efficiency Particulate Air Filter are widely used in dean room environments and other applications that require small paiticle size filtration. HEPA filtration is a relatively new technology in relation to electrostatic precipitation. As with most mechanical filters, HEPA grade filters are made from pleated fiberglass sheets and are over 99% efficient down to .01 microns. HEPA units are more expensive than pre-filters and will become dogged easily if large particles enter the filter fabric It is very important that a series of pre-filters be used with the HEPA filter to extend their lii and reduce maintenance costs.

Figure 3-5 HEPA Filters Diagram



3.2.4 Filtration Selection (Mech. Vs. EPS)

Depending on the type and size of contaminants and concentration levels of airborne particulate, filtration systems may be two-stage, time-stage, or multiple stage. Each stage will contain a filtration device that is designed to capture various sized particles. In the airflow pattern, large paticlee and fibers are collected by the pre-filters and the final fitter Will collect the remaining small particulate. Most welding time filtration systems Will need at least a two stages. The two-stage configuration consists of a pm-filter and final filter with selected efficiencies for the specific application, size of particle and effiency desired. Three-stage filtration consists of a pre-filter, intermediate filter, and a final filter module, which may consist of a 99.97% at 0.1 micron HEPA or an ESP system for small sized partocle applications. Both electrostatic precipitation and high efficiency mechanical filtration technologies can be utilized along with V-Bank cartridge and other pre-filters for a comprehensive multi-staged filtration system. From the previous analysis, it can be determined that a high efficiency HEPA or an electrostatic precipitor (ESP) filter in series with pm-filters are the current alternatives available. Two of the main issues when comparing EPS systems and mechanical HEPA final filtration are the overall reliability and efficiency of the filters and the required maintenance program and associated issues.

Arc welding produces emissions with a wide range of particle sizes. In an ESP filter, larger particles and/or prolonged usage of the fitter will cause bridging across the collection plates, resulting in a reduction in efficiency and a need for continued maintenance and cleaning. The bridge across the plates disables the filtration process. With ESP systems, the fan keeps collecting emissions and discharging them into the local air-space, even if the filtration system is not filtering adequately. The operator must constantly monitor the readings of the filtration unit to ensure that it is operational and performing effcient filtration as needed. On the other hand, when the HEPA filter becomes full, there is a pressure drop that reduces the ability of the collection device to perform its function by reducing collection velocity. In other words, HEPA filters do not lose their effiency, they are slowly dogged and the flow-rate of the collection unit is reduced. Therefore, once the welder notices that the weld fumes are not being collected, the filter must be changed. HEPA filters need to be changed once they are full, which is most likely accomplished by the operator/welder. Much of the literature researched and reviewed favored the use of mechanical filters (pre-fiiters with HEPA) over the use of electrostatic preapitation (EPS) for most welding applications.

3.3 Collection Equipment and Configuration Alternatives

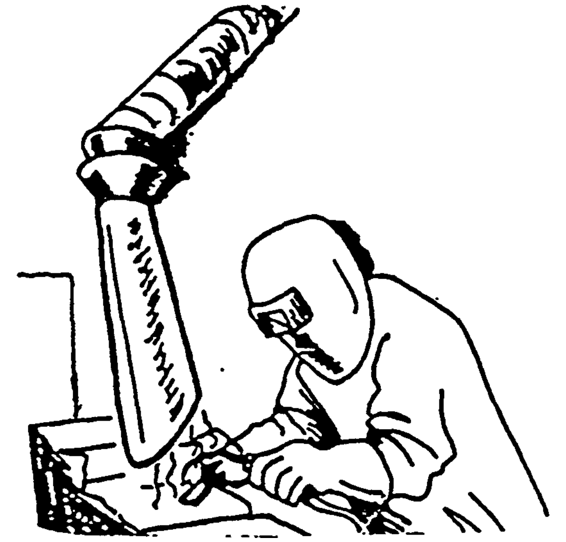
There are essentially two major types of potential emission capturing alternatives available for collection of weld fumes. The first and best alternative is source capture (directly at the point of generation), and the second is non-source capture. Source capture is preferred because of the ability to achieve a higher rate of collection efficiency and the ability to keep potentially harmful emissions away from the workers breathing area. Source capture units are preferred because they can capture a high percentage (>90%) of contaminants, while unducted/non-source capture systems can offer around 75% to 90% effective capture efficiency. There are a wide variety of manufactuers that produce equipment fur both types of capture alternatives. Applying source capture and non-some capture methods to the very difficult applications and industrial settings offered by shipbuilding processes, practices, and facilities is discussed in seotion 3.4 of this chapter. The following section merely provides the reader with a background of weld fume collection devices, systems, and configurations.

3.3.1 Source Capture Systems

Source capture is a technique whereby emissions, generated by porcesses, are collected diractly at the point of generation (i.e. usually within 1 ft of the welding arc). Some people in the industry refer to souce capture as 'local exhaust'. Source capture is the most effective and most widely recommended emissions collection method because it draws off contaminants before they pass through the worker's breathing zone and disperse into the facilities air stream. Source capture techniques are extrnmely desirable in applications where the fumes generated represent significant respiratory or carcinogenic hazard to employees working in the vicinity of generation. Figure 3-6 provides an illustration of a typical source capture system.

Many types of source capture devices (hoods, enclosures, extraction arms, etc.) are designed to capture a high percentage of the fume generation if property used. They rely on movement of air past the generation source at a velocity sufficient to draw the particles to the capture device. The capture velocity and hood design are the basis for all good some capture design. Capture velocity is a large factor in determining how close the device (i.e. capture hood) must be to the point of fume generation. Similatly, the distance between the collection device and the fume genration point is also a driving factor in any efficient time capture system. In fact, the amount of air (CFM) flow-ate required to extract emissions is highly related to the distance of the hood to the point of generation. Therefore, it can be stated that the capture efficiency drastically diminishes as the point of collection is removed from the

Figure 3-6 Typical Source Capture Arrangement



Ventilation Rates for Moveable Exhaust Hoods (OSHA 29 CFR 1910.252)

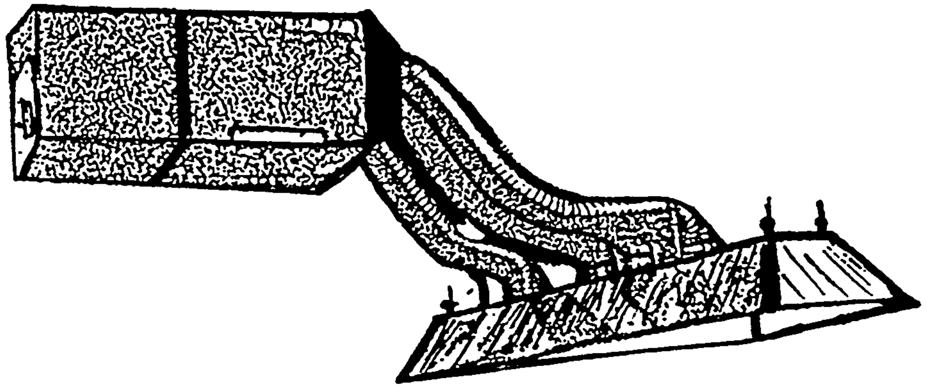
Distance to hood from Arc or torch, (in.)	Minimum Air Flow (ft^3/min)(CFM)	Duct Diameter, (in.)
4 - 6	150	3
6 - 8	275	3.5
8 - 10	425	4.5
10 - 12	600	5.5

point of generation. Table 3-1. outlines some of the guidelines offered by OSHA with respect to flow-rates, ducting diameter, and the distance from the source capture device to the welding arc.

3.3.2 Canopy Capture Systems

If the weld fume generation area is well enclosed, the air contaminant has little area through which to escape. Therefore, a canopy capture system could be used. Contaminated air is drawn up through the hood at high enough velocity to ensure a high percentage of capture. Some effective hood design methods involve enclosing the operation completely with curtains and then providing access openings as required. Canopy hoods are effective for many operations where thermally generated contaminants rise rapidly. Canopy systems should not be used when workers must be positioned directly over the welding process because the flow of contaminated air could pass through a worker's breathing zone. Also, it is recommended that all employees working in canopy collection areas wear proper respirators.

Figure 3-7 **Typical Canopy Hood Arrangement**



3.3.3 Non-Source and Unducted Capture Systems

In many industrial work areas, the best way to capture emission from welding and cutting operations is through a non-source or unducted collection system. Unducted air cleaning systems frequently consist of one or more air cleaning units, positioned in the overhead plant space, to create a planned air circulation pattern, as displayed later in Figure 3.8.

When properly designed, this method cleans the ambient, in-plant, contaminated air. Rather than collecting the fumes at the point of generation, as performed in source capture systems, unducted systems constantly clean the room air stream to remove indoor air contaminants. Unducted systems will never remove 100% of the contaminants in the work area and when potentially harmful contaminants are of concern, employees should wear proper protective respirators.

Source capture systems are the recommended method of air cleaning because they capture contaminants before they can escape into ambient air and potentially into the workers breathing zone. However, there are many factors that can make source capture systems impractical for specific work environments and applications. For example, a non-source capture unducted system could be the best available approach to fume filtration in the five (5) generalized situations presented in Table 3.2

Table 3-2. **Potential Reasons for Non-Source Capture:**
1. Work is performed on large parts and the worker has no fixed operating position, making source capture difficult to impossible.
2. Workers object to hooded systems because of inconvenience. Some source capture systems may require physical positioning by the worker. If it is unlikely the worker will perform required positioning, the system will be rendered ineffective.
3. Areas where several welders are in confined areas requiring an excessive amount of source capture hoods and ducting. The impracticality can potentially escalate to the point that the benefits of source capture effectiveness is eliminated.
4. Ovehead cranes and other mobile machinery make ductwork installation impossible or extremely inflexible. Unducted systems, designed properly, can keep the indoor air cleaning units out of the craneways and still achieve effective air cleaning results.
5. Floor layout revisions are anticipated and could result in expensive ductwork modifications and redesign. Unduoted systems are fiexible and can work in a variety of configurations.

The objectives of non-source capture are to achieve a substantial reduction in air pollutants throughout the indoor work-place and thus reduce the amount of toxic emissions released to the environment from the wok-place.

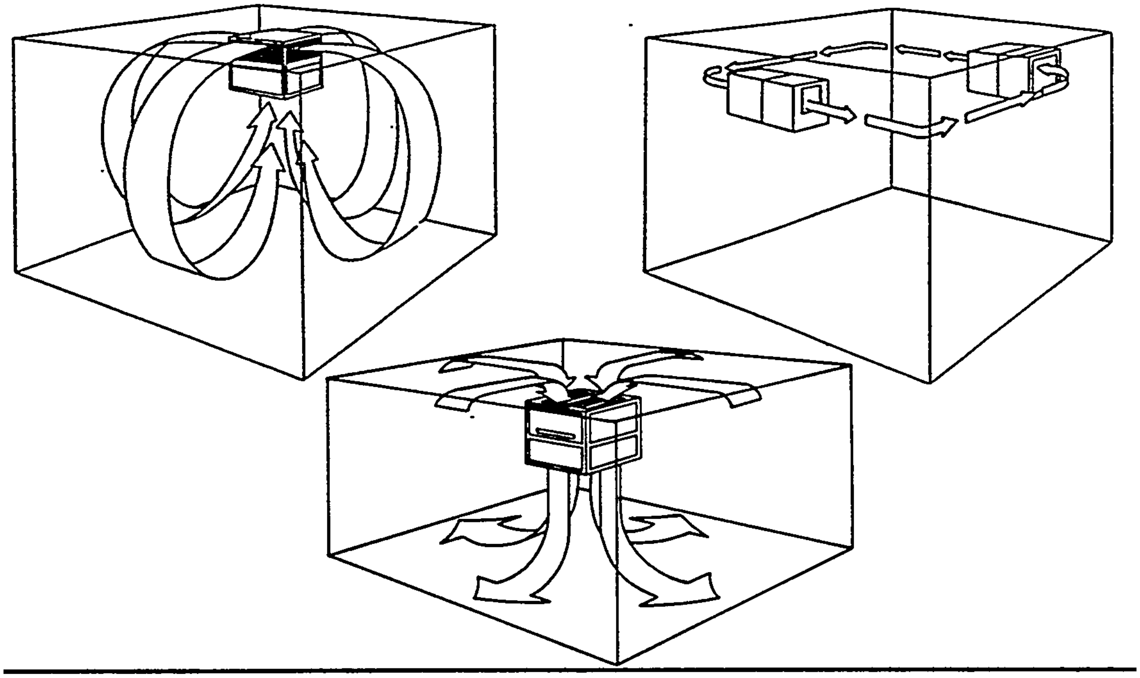
Operation of non-source capture systems will vary from application to application. In overhead systems, welding and cutting fumes rise and are diverted into the collection units air circulation pattern, which are routed to the air cleaning units. Each unit outlet “throws” or “pushes” the contaminated air toward the other units inlet where the air is drawn in and treated.

Self-contained non-source capture unit mounting heights should be from 9 feet to 15 feet above the floor, regardless of the rooms ceiling height. An air pattern created at that height circulates air from both upper and lower spaces. Minor amounts of contaminants and gases can be expected to rise above the air pattern, which will likely be captured at later time. By consistently removing contaminants from the room, unducted systems prevent build-up and subsequent contaminant “stacking” of pollutants down to the floor level. Air quality control engineers, employed by the multitude of air filtration manufacture, will help design systems to meet individual mom configurations and work environment needs.

3.3.4 Standardized Equipment Configurations Available

Indoor air collection and filtration control equipment are manufactured in a variety of configurations for a variety of applications. For simplicity, collection and filtration systems can be divided into self contained fan/filter units and modular systems. Self-contained collection and filtration units are very popular throughout industry. They are typically pm-designed arrangement with optional filtration types and efficiencies. On the other hand, many systems are designed in a modular fashion, to customize systems for a variety of applications and efficiency requirements. The following two sections briefly describe the two general categories of equipment that manufacturers have designed to solve industrial weld fume collection and filtration problems. After the introduction of the standardized equipment,

Figure 3-8 Typical Non-Source Capture Arrangement



Section 3.4 idenfies how standardized and modified equipment could potentially be adapted to shipyard industial settings.

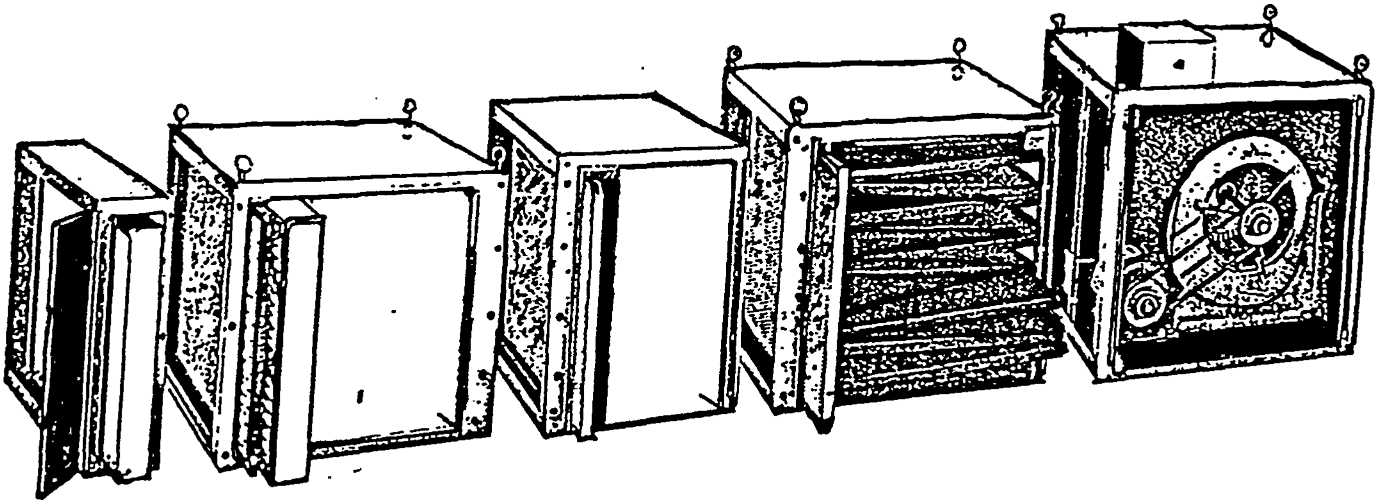
3.3.4.1 Self-Contained Fan/Filter Units

Many types of self-contained fan/filter units are available and in many cases, are the simplest form of industrial weld fume collection and filtration offered. Systems are available with a variety of filters (V-Bank, HEPA, EPS) and remove particles in a wide variety of sizes. The most popular system involves a single collection arm and hood that collects fumes and particles at the point of generation and filter the air as displayed in figure 3.11.

Most systems work by passing contaminated air through a cabinet with a pre-set filter arrangement. The cleaned air is then returned to the work-space. Therefore, if the unit releases treated air indoors, one must ensure that the air is breathable according to OSHA indoor air quality standards. This type of equipment configuration is available in a wide range of source and non-source capture configurations that can be applied to different work environments.

Self-contained units range in capacity from 300 to 6,000 CFM. The units are supplied complete with their respective filter components and motor/blower drive sets, in self-contained cabinets, made from industrial high gauge steel. Accessories and options can include automatic filter cleaning systems, inlet and outlet plenums, source capture hoods and arms, pre-filters, main-filters and after-filters. Self-contained units can be “free-hung”, in a non-source capture configuration, to clean and recirculate difty air, without use of ductwork, hoods, pickups or enclosures. Units can also be directly ducted to the source of fume development (i.e. the welding arc). The systems mentioned above can provide source capture with extraction arms and in many cases, the systems are light, have wheels and are portable.

Figure 3-9 Typical Modular System Configuration



3.3.4.2 Module Configurations

Equipment is available in modular configurations with air volumes ranging from 1,000 to 30,000 CFM. These systems feature standard components, arranged in a modular design, for customized applications. The modules allow for flexibility in the design and application of collection and filtration to various industrial settings The modules include a fan equipment module and a variety of filter sections including: V-Bank filters, HEPA filters, ESP systems, and others. The modules are bolted together and arranged for either source or non-source capture. Modular systems can include options such as in-place cleaning systems and sophisticated diagnostic efficiency indicator devices. Figure 3-9 provides a good illustration of a typical modular type system.

3.4 Applicability of Collection Equipment

Shipbuilding and repair processes, operations, and facilities were investigated to evaluate the feasibility of collecting and filtering welding fumes and particulate emissions. Results from the shipbuilding and repair process investigations are presented as Appendix A and serve as the basis of understanding for the feasibility analysis. Shipyards have very unique facility and process circumstances that make it extremely difficult to collect welding emissions at a variety of production locations throughout the shipyard. Applying source capture and non-source capture methods to the various applications and industrial settings, offered by shipbuilding processes, practices, and facilities is a challenging task that can cause production problems and be potentially expensive.

Several weld fume collection and filtration equipment vendors were contacted to investigate standardized equipment availability and determine how their equipment could be applied to the shipyard applications. Flexible equipment configurations that could be customized for specific production situations were also investigated. There are no simple solutions to collecting welding fumes in the shipyard environment. Similarly, there is clearly, not one single collection configuration solution that can be applied to all shipyard areas or to shipyards with diverse facilities and production constraints. Each facility and production situation must be handled on a case by case basis.

All areas and processes in the shipyard have their own unique set of constraints and potential collection alternatives. Open areas

Table 3-3 Potential Alternatives to Weld Fume Collection

Potential Collection Systems:	**Potential Area or Process Applicable in the Shipyard**
1) End of the Line Filtration	Shops and welding area booths
2) Portable Roll Around Units with 6 to 14 ft. of Arm Reach	Shops, welding area booths, some open areas, some confined spaces
3) Portable Vacuum Units Connected to Weld Guns (Up to 100 ft. of reach from fitter unit)	Confine spaces with MIG guns, Open areas, some shops
4) “Hand Held" Light Weight Portable Units Vacuum/Filtration Units	Small jobs with weld electrodes requiring portability
5) Canopy Hood Collection With or Without Curtains (Area Capture)	Good for cutting machines, some shop configurations
6) Non-source Capture Modules	Confined spaces, some indoor weld stations

such as panel lines, assembly areas, rotary turntables, and pin jigs pose unique collection constraints. Similariy, enclosed areas including pipe shops, machine shops, welding schools, and sheet metal shops, have a different set of collection alternatives available. In addition, confined spaces on-board ships and during instruction may require customized equipment and production adjustments. Table 3.3 outlines six (6) potential alternatives derived from manufacturers and equipment supplier surveys and shipyard prcoess research and investigations. Each of the potential collection systems mentioned are described along with their operational pros and cons in the following six sections.

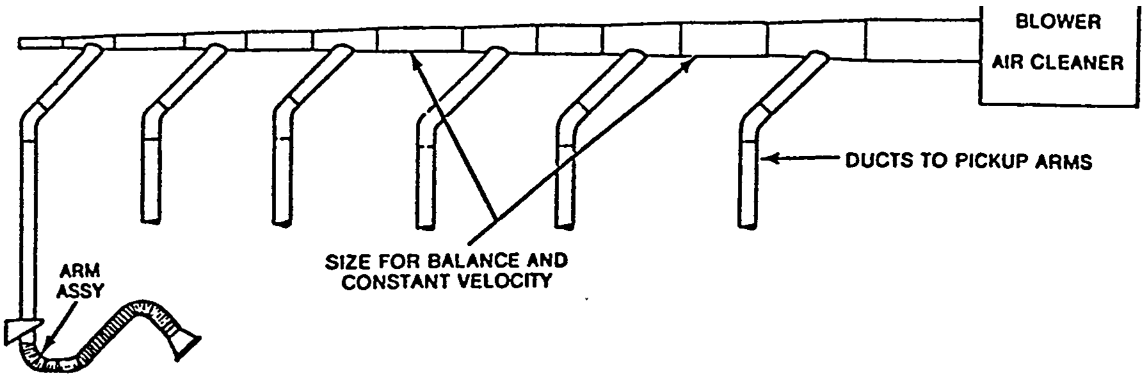
3.4.1 End of the Line Filtration

End of the line filtration is a description used to explain a filtration solution designed for enclosed buildings, with multiple weld stations, where a large filtration unit could be installed on an existing fume collection system. Some shipyard shops have, or could install weld exhaust collection systems that collect welding emissions from weld stations and discard the emissions into the atmosphere. Figure 3.10 displayed a typical multiple collection system configuration. Multiple station systems are common and generally in place to capture the fumes and divert contaminated air from the welders breathing area for Occupational Health and Safety (OSHA) purposes. The systems are excellent for maintaining and otherwise managing indoor air quality in workshops with welding operations, provided the collection systems are designed and used properly. Multiple station collection systems are applicable to several indoor shipyard shops (i.e. pipe shop, sheet metal shop, metal fabrication, etc.) throughout the shipyard.

3.4.1.1 Operational Pros

In many cases throughout the shipbuilding industry, a portion of the welding occurs in shops and other enclosed facilities were emissions are already collected and pulled away from the welders breathing area. If weld stations exist with a collection system, a filtration improvement could be a “bolt-on” solution that does not interfere with production operations within the facility. Therefore, this solution alone could minimize a good portion of the facilites toxic welding emissions. End of the line filtration is an excellent method to minimize the amount of weld fume emissions released into the environment without filtration. Therefore, welding emissions to the environment will be

Figure 3-10 Multiple Station Collection Station ***(AirFlow Systems*** **Inc.)**



minimized **to the extent of efficiencies achieved** by the collection and filtration devices installed. The only major operational change is that the filtration unit will need to be maintained frequently depending on the quantity of material welded, filtration capacity, and the maintenance schedule prescribed by the manufacturer.

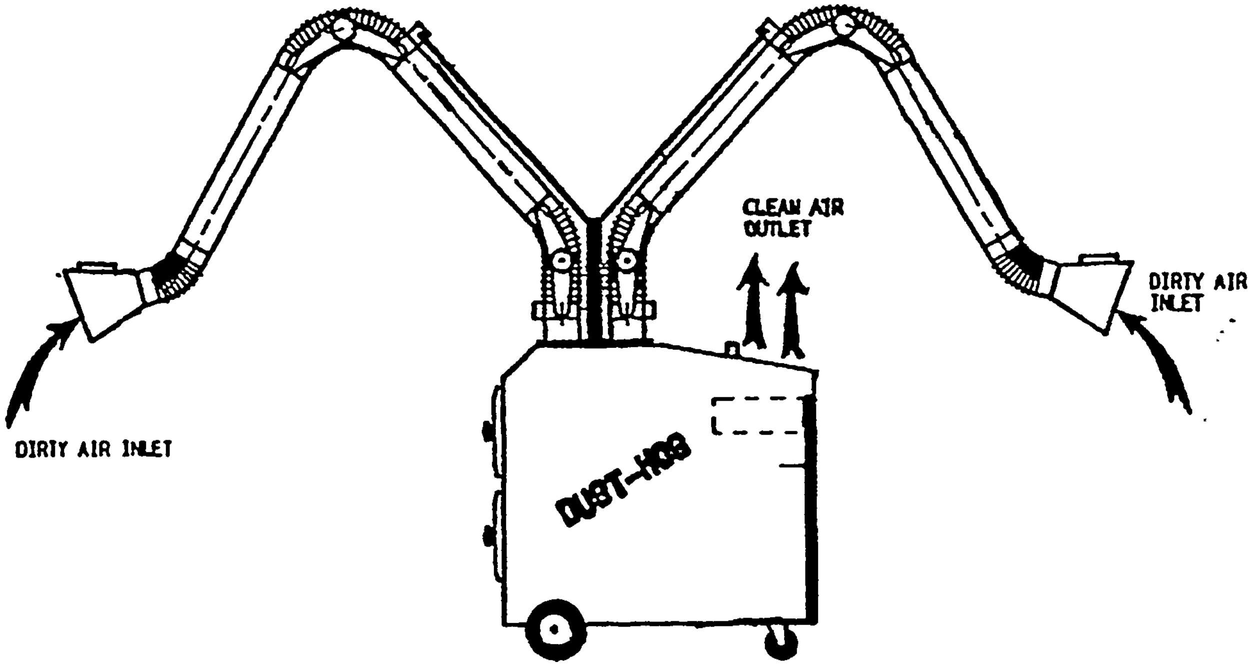
3.1.1.2 Operational Cons

The main problem is that systems require continuous and potentially expensive maintenance cost for cleaning, replacing and disposing of filters. This solution will collect all types of weld fumes created in the environment from which it is associated (i.e. mild steel, copper nickel, stainless steel, etc.) and will not be used exclusively for potentially 'toxic" emission sources (i.e. hexavalent chromium). Therefore, the maintenance expense may be great because of the large quantity (lbs) of emissions filtered by the system. Therefore, it would be important to have a less expensive prefilter arrangement to minimize costs.

3.4.2 Self Contained Roll-Around Units (With 6 to 14 ft. of Arm Reach)

Portable roll-around units are widely used for in-door industrial activities because of their availability and applicability to many welding operations throughout industry. There are numerous manufacturers of such equipment and their electrical, physical, mechanical, and operational characteristics vary greatly. The roll-around units are "stand-alone"

Figure 3-11 Self Contained Roll-Around Unit



collection and filtration systems with one or two collection arms as displayed in figure **3.11. The** collection hood arms generally range from 6 to 10 ft. in total reach. Most of the systems are designed and tested and provide analytical data on their filtration and collection efficiency rating.

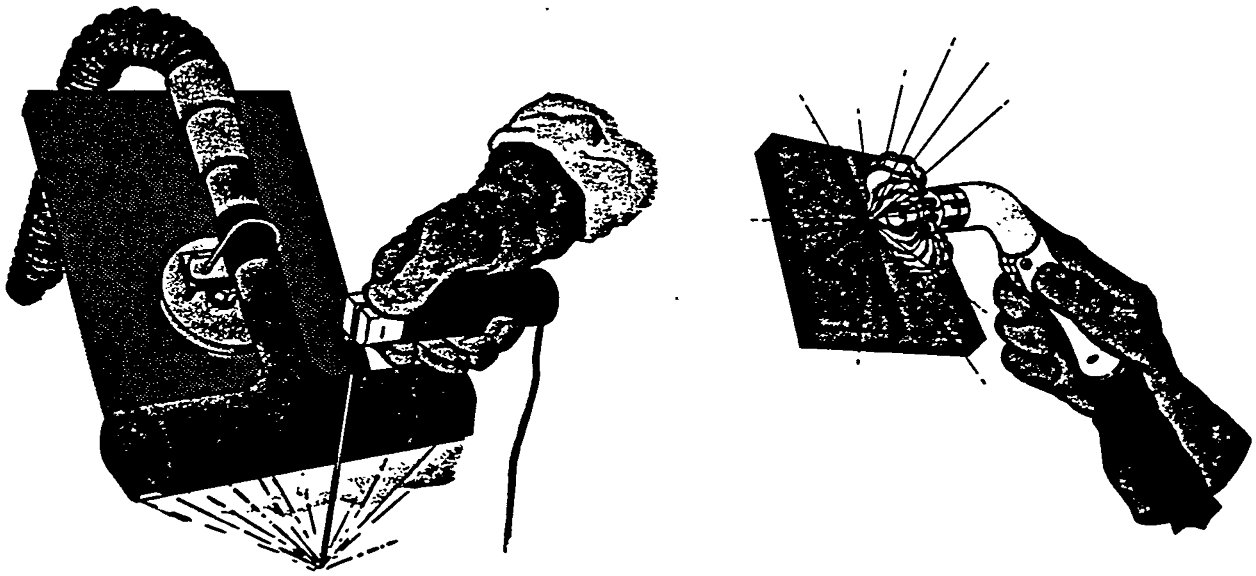
3.4.2.1 Operational Pros

This option works best for collecting fumes at specific weld stations in shipyard shops and some outside areas that have smooth floor surfaces and accessibility. The smaller units have less maintenance requirements because they could be used to filter specific potentially harmful weld fumes (i.e. weld fumes containing Cr^6 or Cadmium). Many of the roll around units are very efficient collection and filtration systems. If a shipyard controls and directs welding with electrodes and wires containing potentially harmful fumes to roil-around units, emissions may be mitigated. In addition, If the majority of potentially harmful emissions from welding occurs inside the shops with smooth floors, this alternative is very attractive for reducing emissions.

3.4.2.2 Operational Cons

The applicability of the roll-around units to the shipbuilding industry is limited by a variety of operational and physical constraints. For the roll around units, portability is limited to areas in the shipyard with floor surfaces that can handle a 250 to 500 lb. cabinet (approx. 5' X 3' X 4') with 6 to 8" industrial casters. In many cases, hoses, electrical cords, pot holes, steps, large cracks in the flooring and a variety of other objects, will be a deterrent to moving this unit to and from stations that require fume emission filtration. The extraction arms average around 8 ft. in length (available length are up to 14'), which tends to be another drawback that limits the applicability of this option to anything but the indoor shops and some unique outdoor applications. Outdoor and indoor areas, where very large workplaces are welded and assembled, provide a challenge to these units because of their limited reach and portability.

Figure 3-12 Weld Gun Units



Another important operational constraint is the fact that shipyard management could need to direct potentially harmful welding processes to the roll around units or direct the units to the toxic welding locations. Directing specific weld rods, wire and electrodes to specific locations with weld fume collection machines, would be an operational constraint to most shipyards. Increased planing, predictability and a high level of production control on the part of the shop manager with respect to welding stations, job-type planning, and specific welding needs is required.

3.4.3 Vacuum **Units Connected to Weld Guns**

There are several manufacturers that build vacuum units that connect directly to MIG type weld guns (automatic wire feed with gas shielding). Some manufacturers are attempting to design collection systems at the point of generation near the weld arc for SMAW welding processes with limited success. Collection hoses on these units connect to the gun and run back to an individual self contained unit about the size of an average arc welding machine as displayed in figure 3-12. The units have a reach from 25 to 50 ft from the filtration unit and many systems have the ability to handle 1 to 4 weld guns. The size and weight are very similar to the roll around units and frequently come with casters for **mobility. To** eliminate problems with sizing proper velocities and fan motor requirements, it is recommended that maximum horsepower units are best for enjoying the fiexibility offered by this type of option.

3.4.3.1 Operational Pros

It appears that this option may be a good solution to the problems of ensuring that the welders are using the collection and filtration systems because the collection system is attached directly to the weld gun. For example, when the units are used correctly, they can collect fumes in several welding position (i.e. down-hand, vertical, and overhead), which is difficult to perform with other types of fume collection. Although, vertical welding is not as efficient with gun collection systems. These systems have good range abilities for on-board and on-block applications where MIG type guns are used because the filtration unit can be placed as far as 60 ft. from the welder.

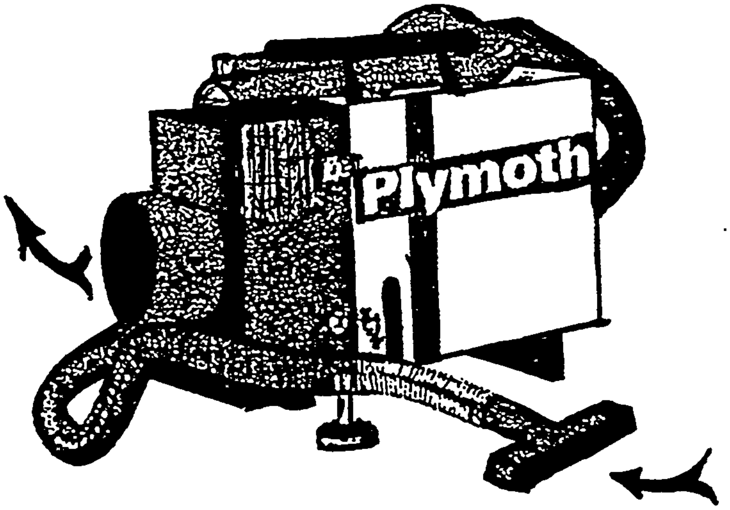
3.4.3.2 **Operational Cons**

One of the main concerns about this option is that it is only applied to GMAW automatic wire feed type welding equipment. A good portion of potentially harmful fumes are derived for SMAW processes and they can also be a majority of the shipyard emissions. Some work has been devoted to developing a system for the SMAW process with limited success. The main operational problems have to do with the weld gun becoming too bulky to perform high quality welding and the distance from the arc to the weld gun can be 14”, at times, requiring a large diameter hose with very high velocities. Many of the welders find the attachment for MIG and SMAW guns very bulky, which impairs the welders visibility. Therefore, welding with collection units connected to the weld guns could yield reductions in weld quality and overall production rates.

3.4.4 **Light Weight Portable Vacuum - Filtration Units**

Several manufacturers offer light weight portable vacuum and filtration units as a solution to mitigating potentially toxic emissions. The units are essentially a vacuum cleaner with an electrostatic cleaner or a mechanical filter. They are applicable to a wide variety of areas in the shipyard and propose to be a mobile solution to temporary work station emissions collection needs. These systems come in various sizes and efficiencies and are light enough for one or two workers to transport throughout production areas, as needed. The systems are generally designed with a 2" to 3" diameter hose with approximately 10 to 25 feet of length. Figure 3.13 displays a light weight portable type system.

Figure 3-13 Light Weight Portable Unit



3.4.4.1 Operational Pros

Small portable systems have potential to help in areas that are confined and have very limited amount of welding (i.e. maintenance or small jobs). Their main strong-suit for these systems are their light weight and portability, which-allow them to be used in a wide variety of locations in the shipyard These systems could be useful in situations where harmful emissions need to be captured on an as needed basis.

3.4.4.2 Operational Cons

On the surface, these systems seem as if they could apply to a variety of shipyatrd cofigurations, although in reality, this is not the case. The small portable system are not extremely practical **in that they require the** welder to constantly move the unit because of the limited amount of reach capabilities and positioning of the collection apparatus. The filtering capabilities, durability, and collection velocities of these systems are essentially exchanged for their light weight. Therefore, application of these systems should be considered on a case by case basis.

3.4.5 Canopy Hood Collection With or Without Curtains (Area Capture)

Canopy hoods are used throughout industry, with or Without curtains, to control emissions from specific processes. Canopies offer a good combination between source and non-source capture in that fumes can be collected and filtered in the canopy or the canopy can be used as the collection funnel for source capture. The systems are most applicable to continuous operations occurring at the same location although, some portable canopy arrangements could be designed for a variety of applications in the shipyard environment. The indoor small canopy design applies to shipyards mainly in production shops. If a curtain is used, the system basically tents the operation and increases the collection efficiency of the canopy hood. Canopies may also be designed to be applied to a variety of large outdoor or indoor applications. The canopies could be designed to be portable, for outdoor yard-wide usage, and can be designed in one of the following configurations 1) utilize

non-source capture **within the canopy, 2)** have **a flexible ducting system within the** canopy along with non-source filtration, or 3) as a funnel to extract and filter contaminated air. Care must be taken with respect to worker protection in these types of configurations.

3.4.5.1 **Operational Pros**

The canopy alternatives provide a combination of usability and applicability to some shipyard weld fume collection needs. Indoor canopy systems are good for localized work in certain areas of the shipyard shops where source capture is undesirable.

3.4.5.2 **Operational Cons**

As with many of the options concerning the collection of specific emissions, shipyard management must understand that the system is available and it must be used as necessary to minimize potential release and protect employee health. Production planning will be required whenever specific jobs must include the addition of weld fume collection devices in the production process. In some shipyards this could be a real operational constraint due to a lack of production control. Planning, predictability and a high level of production control on the part of the shop manager is required when it comes to integrating this type of system into the shipyard operations.

3.4.6 **Non-Source Capture Modules**

Non-soure Capture modules were discussed earlier and have some potential for application in the shipbuilding and repair operations. The units are “stand-alone”, in that they take in contaminated air from the room environment, filter the air, and exhaust it back into the room environment. The exhaust generally causes an air pattern to direct other fumes back into the intake. Non-source capture modules are available in a wide range of sizes and shapes and can be mounted in a variety of locations. Essentially, the systems pull in contaminated air, filter it, and release it. The systems could be applied to confined spaces or rooms on-board ships. To ensure that employees are protected from potentially harmful fumes, respirators and other protective equipment should be used. The effectiveness efficiency of the system is dependent on the systems capture efficiency (i.e. percentage fumes being filtered), which is a function of good design.

3.4.6.1 **Operational Pros**

The non-source capture systems are mainly stationary and permanent. Although, with some effort and design, systems could be made to be portable and applied to confined spaces (i.e. machinery spaces, stainless exhaust stacks etc.). The complete system could be packaged to be transported by forklift and lifted on ships via cranes. The weight of the systems range form 350 to 700 lb. depending on system configuration and specific packaging.

3.4.6.2 **Operational Cons**

The systems are not factory designed to be portable and if they are not setup properly, they can exhibit poor collection efficiency. They may require systems to be designed vertically or with an extraction element that could extend to the ceiling to capture and filter fugitive weld emissions. As with many of the options concerning the collection of specific emissions, shipyard management must use the system maintain it as necessary to minimize potential release and protect employee health.

Chapter 4.

Arc Welding
Emission Factor Information

4.1 Introduction

As potentially harmful emissions from electric arc welding operations are becoming an environmental issue, the EPA Office of Air Quality Planning and Standard Emissions Inventory Branch, State Air Resources Boards, Air Quality Management Districts, and industry are striving to develop emission factors to quantify emissions. Similarly, OSHA and occupational health and safety officials/representatives, NAVSEA, and industry are also heavily involved with welding emissions from the standpoint of the welder exposure levels. At present there is somewhat limited data available for developing standard emission factors for specific processes and electrode types. Current technical reports and literature contain emission data for selected rods, electrodes and wires under limited variations in operational settings. In some cases, even the fume sampling protocol is under scrutiny. Even with the limited data, emission factors have been developed, and this chapter provides an introduction to the most current arc welding emission factor information available.

4.2 Background

In eleotric arc welding, the resulting high temperature melts the consumable Wire or rod and heats the work-pieces, which enables fusion and joining of the metal parts. The rising plume of heated air forms a high local concentration of a complex mixture of gases, oxides, and other metal compound particulate matter (PM). It is generally accepted and validated in the technical literature that anywhere from 0.5 to 3.5 percent of the consumable welding electrode is converted to particulate matter (PM) emissions (commonly called weld fumes), depending on the process type. The amount of rod converted to time is called the Fume Generation Factor (FGF) or Fume Formation Rate (FFR) and is presented as a percentage fume to rod (Lb. fume / Lb. rod). The quantity and chemistry of the fume is dependent on the type of welding process, electrode composition, and to a lesser extent a variety of other operational variables such as voltage, shielding, polarity, and current.

Consumable electrode, rod, and wire material composition are selected to be metallurgically compatible with the wok-pieces being joined, which helps ensure proper fusion and strength of the weld. Throughout the technical literature, it is commonly accepted that vast majority of the fume composition is determined by the electrode. The consumable electrode or wire component is the primary source of the fume because the entire rod reaches very high temperatures at the arc, whereas the weld pool and portions of the materials joined are not brought to such high temperatures. The realization and acceptance that weld fumes are driven mainly by the electrode composition is central to the interpretation of data and the derivation of emission factors.

Due to the variety of welding operational scenarios, welding processes, and electrode types, universal emission factors need to be developed for the different processes and the emission constituents of concern (i.e. hexavalent chromium, nickel, lead, etc.). Metals within welding rods have different melting points and boiling points. Specific emission quantities of the metals will depend on the individual metals' physical characteristics as well as welding process variables such as gas shielding or flux coat shielding. At this time, chromium, hexavalent chromium, manganese, lead, cadmium, manganese and nickel are the main metal emissions of concern with environmental and health agencies.

Most emissions are treated as very small metal particulate released into the local air-stream. However, hexavalent chromium is different Emissions of hexavalent chromium, as compared to nickel and others, are complicated by the fact that a specific valence state of chromium is the focus of interest. The oxidation/reduction reaction rate and chemistry make the emission rate strongly dependent on the environment in which the reaction takes place. It is also interesting to note that hexavalent chromium is relatively unstable as an aerosol in the presence of a number of atmospheric pollutants. The Research Triangle Institute (1988) measured the degradation rates in laboratoty and field tests, and reported an average hatf-life of 16.4 hours (+/- 6.9 hours). A half-life that is sufficiently short will have limited effect on the environment This fact can be very important when performing health risk assessments for the local areas around which hexavalent chromium is emitted.

4.3 Available Information on Arc Welding Emission Factors

Emission factors for electric arc welding are in the early stages of development Limited emission data is available and form the basis for deriving general factors to quantify emissions. This section provides the majority of arc welding emission data and explains the derivation of emission factors by National Steel and Shipbuilding Company (NASSCO), California Air Resources Board (CARB), SARA Title III Toxic Release Guidance Document and the Proposed Federal AP-42 Section 12.19 on arc welding emission factors.

4.3.1 NASSCO Developed Emission Factors

In 1992, National Steel and Shipbuilding Company (NASSCO), in conjunction with Dr. Richard L. Bell of Adams, Duque, and Hazeltine (AD&H), performed extensive research and analysis of available information on welding emissions to derive improved emissions factors for shipyard welding operations. Dr. Bell was assigned to research hexavalent chromium and nickel. The methodology and resulting emission factors derived by Dr. Bell are scientifically and statistically sound considering all of the available information. This section summarizes reports submitted by Dr. Bell.

An extensive literature search was performed at the University of California at Los Angeles library, and through other sources, to develop a database of information pertaining to welding technology, chemistry, emissions, and exposure. In addition, reports from the American Welding Society (AWS), the Environmental Protection Agency (EPA), and the San Diego APCD were used as data sources. Due to the various combinations of electrode composition, welding processes, and various welding process variables, the possibility for thousands of different welding environments in the shipyard exists. To develop generalized emission factors for the various welding processes, a statistical analysis was performed on the data provided by the weld emission technical reports and studies researched.

The research yielded that from the perspective of emissions formation, welding processes can be differentiated into two broad categories on the basis of the welding process employed and how the arc is shielded from the atmosphere. The two broad categories of welding processes are refereed to as Gas Metal Arc Welding (GMAW) and Shielded Metal Arc Welding (SMAW). The GMAW category applies to welding processes that generally uses a continuous uncovered wire, where the arc is shielded by a gas stream supplied by the weld gun. The GMAW process category includes variations such as Flux Cored Arc Welding (FCAW) and Gas Tungsten Air Welding (GTAW). On the other hand, the SMAW category is characterized by welding electrodes covered by a solid flux coating that is vaporized in the arc to provide shielding from oxidization. The chemistry of the shielding gases depends largely on the composition of the flux around the rod. Although the fume chemistry in SMAW and GMAW processes is not completely understood, research indicates that the differences between the two process methods employed, result in metal emission factors that are significantly greater for the SMAW than for the GMAW process.

4.3.1.1 Emission Factor Development

Table 4.1 displays the primary information used to determine standardized emission factors. The goal was to develop emission factors that could be used throughout the shipyard for various welding rods and processes. It was intended that the shipyard would only need to supply the following information in order to quantify emission of a certain metal:

1) Quantity of Rod Used
2)* Process Type (GMAW or SMAW)
3) Composition of Welding Rod (i.e. % chrome)

* The process type determines which emission factor to be used.

Table 4.1 presents the "master list' of chromium welding emission data used by Dr. Bell. The majority of the data presented in the table is derived for the American Weld Society (AWS). Two AWS reports were used; Fumes and Gases in the Welding Environment (1979) and an unpublished document that yielded statistically consistent values for similar welding rods and processes. Other reports, referenced at the end of this chapter, authored by J. Mitti, R.M Stem, E. Tompsen, and information presented by Tomas Weeks, San Diego Air Pollution Control District were also used. The master data set presented in Table 4.1 has several locations where data was not available from the respective studies. As will be discussed later, averages were used to fill in the missing data and a statistical analysis was performed to validate the averaged values.

Table 4-1 Dr. Bell's Master Data Set For Chromium Emission Factor Development

Source	Rod Type	Welding Process	% Cr in Rod	% Rod to Fume	% Cr in Fume	% Cr^{+6} in Fume
AWS (1979)	E316-15	SMAW	18.7	0.71	5.80	na
AWS (1979)	E316-16	SMAW	18.7	0.60	6.50	na
AWS (1979)	Haynes 25	SMAW	20	0.65	6.90	na
AWS (1979)	Inc 625	SMAW	21.5	0.70	5.90	na
AWS (unp)	308L-16	SMAW	19.0	0.40	na	4.50
AWS (unp)	293	SMAW	23.5	0.50	na	3.80
AWS (unp)	316L-16	SMAW	18.5	0.70	na	4.70
AWS (unp)	331	SMAW	19.5	0.75	na	5.10
Mitti (1979)	na	SMAW	20.3	na	2.99	2.01
Stem (1979)	na	SMAW	19.642	na	6.00	4.50
Stem (1981)	na	SMAW	19.642	na	6.40	4.30
Tola (1977)	na	SMAW	18.00	na	3.57	2.68
Weeks	na	SMAW	18.0	na	6.00	na
Weeks	na	SMAW	20.0	na	6.00	na
AWS (1979)	E316T-3	GMAW	18.7	0.84	12.50	na
AWS (1979)	Inconel 625	GMAW	21.5	0.08	15.40	na
AWS (1979)	Haynes 25	GMAW	20.0	0.13	14.90	na
AWS (1979)	Haynes C276	GMAW	16.0	0.69	8.20	na
AWS (unp)	308L	GMAW	20.8	0.35	na	0.700
AWS (unp)	309L	GMAW	24.0	0.47	na	0.800
AWS (unp)	316L	GMAW	19.0	0.33	na	0.700
Mitti (1979)	na	GMAW	20.1	na	6.45	0.580
Thompsen (1979)	na	GMAW	19.375	na	13.80	0.320
Weeks	na	GMAW	15.0	na	3.90	0.620

In the case of chromium, the fraction of chromium that exists in the hexavalent state is strongly dependent on the welding process generating the emissions. The data included in Table 4-1 is sufficiently complete to account for and support the emission factor differences between the welding processes. The data from Table 4.1 was separated into the two welding processes; GMAW and SMAW. The following five parameters were then used to calculate the hexavalent chromium emission factor:

1) the fraction of chromium (% Cr in Rod) in the electrode
2) the fraction of the electrode emitted, fume formation rate (FFR) (% Rod to Fume)
3) the chromium content in the fume (%Cr in Fume)
4) the chromium content in fume compared to content in rod (% Cr fume / % Cr in rod)
5) the hexavalent chromium in the fume (% Cr^{+6} in Fume)

Hexavalent Chromium Emission Factor

EF = (FGR - lb. fume/ lb. rod)(%) * (Fume Composition - Cr in fume / % Cr in rod) * (Hexavalent Portion of Chrome Emission - % Cr^{+6}/ Cr in fume)

EF Units = (lb. fume/ lb rod) * (Cr^{+6} / %Cr in rod)

Table 4-2 Data for Hexavalent Chromium Emission Factor Development for SMAW Welding Operations

Source	Rod Type	% Cr in Rod	% Rod to Fume	% Cr in Fume	% Cr^{+6} in Fume	% Fume to Rod Cr	% Fume Cr+6/Cr
AWS (1979)	E316-15	18.7	0.71	5.80	3.949	31.02	68.08
AWS (1979)	E316-16	18.7	0.60	6.50	3.949	34.76	60.75
AWS (1979)	Hay 25	20	0.65	6.90	3.949	34.50	57.23
AWS (1979)	Inc 625	21.5	0.70	5.90	3.949	27.44	66.93
AWS (unp)	308L-16	19.0	0.40	5.606	4.5	29.51	80.27
AWS (unp)	293	23.5	0.50	5.606	3.80	23.86	67.78
AWS (unp)	316L-16	18.5	0.70	5.606	4.70	30.3	83.84
AWS (unp)	331	19.5	0.75	5.606	5.10	28.75	90.97
Mitti (1979)	na	20.3	0.626	2.99	2.01	14.73	67.22
Stem (1979)	na	19.642	0.626	6.00	4.50	30.55	75.00
Stem (1981)	na	19.642	0.626	6.40	4.30	3258	67.19
Tola (1977)	18	0.626	3.57	2.68	19.83	75.07	na
Weeks	na	18.0	0.626	6.00	3.949	33.33	65.81
Weeks	na	20.0	0.626	6.00	3.949	30.00	65.81
Average	in Data Set	9.642	0.626	5.606	3.949	28.65	70.85

Table 4-3 Data for Hexavalent Chromium Emission Factor Development for GMAW Welding Operations

Source	Rod Type	(%) Cr in Rod	(%) Rod to Fume	(%) Cr in Fume	(%) Cr^{+6} in Fume	(%) Fume to Rod Cr	(%) Fume Cr+6/Cr
AWS (1979)	E316T-3	18.7	0.84	12.5	0.620	66.84	4.96
AWS (1979)	Inconel 625	21.5	0.08	15.4	0.620	71.63	4.03
AWS (1979)	Haynes 25	20.0	0.13	14.9	0.620	74.50	4.16
AWS (1979)	Haynes C276	16.0	0.69	8.20	0.620	51.25	7.56
AWS (unp)	308L	20.8	0.35	10.736	0.700	51.61	6.52
AWS (unp)	309L	24.0	0.47	10.736	0.800	44.73	7.45
AWS (unp)	316L	19.0	0.33	10.736	0.700	56.50	6.52
Mitti (1979)	na	20.1	0.413	6.45	0.580	32.09	8.99
Thompsen 79	na	19.375	0.413	13.80	0.320	71.23	2.32
Weeks	na	15.0	0.413	3.90	0.620	26.00	15.90
Average	in Data Set	19.375	0.413	10.736	0.620	54.64	6.84
Standard Deviation	in Data Set	2.73	0.26	4.19	0.17	15.99	3.56
Percent STD	in Data Set	14.07	62.37	39.07	26.68	29.27	52.06
Standard Deviation	in Data Set	1.53	0.11	1.21	?	5.47	8.84
Percent STD	in Data Set	7.77	17.99	21.61	23.34	19.10	12.48

Each data set (row) contained at least two of the four parameters needed. Emission data sets, without emission data, were filled using the average of the existing data in each category. Once the data sets were filled with averages, the fume chromium to rod chromium percentage was calculated. Assuming this value is process dependent, it can be used for calculating the fume chromium from chromium containing welding rods. The second important parameter calculated, was the percentage of fume-chromium that is in the hexavalent state (Cr VI). These two parameters are shown as derived values in Tables 4-2 and 4-3. The results indicated, that the amount of chromium in the fume from the SMAW process is about one-half of the GMAW process. At the same time, the fraction of chromium in the hexavalent state, in the SMAW process is more than an order of magnitude greater than in the GMAW process. Therefore, it validates the assumptions that the amount of chromium in the hexavalent state is a function of welding process and associated shielding techniques.

Some emission factors may attempt to assume that the % metal in the fume is equal the % of the metal in the rod. This assumption of direct proportionality (i.e. fume composition = same as rod composition), is strongly disputed by all of the data available on weld rod emissions. For example, for rod 308L-16, chrome represents 18.7% of the solid electrode content, while chrome only represents 5.66% of the fume composition. Both chromium and nickel analysis dispute the direct proportionality assumption. Therefore, Dr. Bell determined average proportionally and incorporated them into the emission factors as presented in Table 4.4 and Table 4.5.

Table 4-4. NASSCO Derived Hexavalent Chromium Emission Factors

Emission Characteristics	SMAW	GMAW
1) (FGR) Fume Generation Rate (lb. fume/ lb. rod) (%)	0.626%	0.413%
2) Fume Composition (Fume Cr as a % of Rod Cr)	28.65%	54.64%
3) % Cr^{+6}/ Cr in fume	70.85%	6.84%
Emission Factor (EF) (* Product of above)	0.00128	0.000154

* Emission Factor has been converted to a fraction

Example Emission calculation:
-Assume 500 lb. usage of Rod 1500, mii-308
-Welding Process = GMAW
-Rod % Chrome = 20.75%

Hexavalent Chrome Emission = (AU)*(Rod % Metal)*(EF)
where:
(AU) = Annual Usage (Issued weld rod minus estimated waste)
Rod % Metal = Individual Rod Metal Concentration (%) of rod (certifications or MSDS') (lb. metal per lb. rod)
(EF) = Emission Factor GMAWCr^{+6} (From Table 4-4 above)

Therefore,
Hex-Chrome Emission mil-308
= (500 lb.)*(20.75%)*(0.000154)
= Emission= 0.016 lb.

Nickel Emission Factors

As with the information for the chromium emissions, the data for nickel was aggregated according to welding process types. This database contains data from stainless steel electrode with nickel content in the 10 to 13 percent range and also from high nickel electrodes in the 54 to 58 percent range. Data for both nickel levels was available for the SMAW and GMAW processes. Table 4-5 below represents the results of the nickel emission factor

The FGR's (percent of rod converted to fume) shown in Tables 4-5 is a subset of the data base shown in Table 4-1 and 4-2. It is not surprising that they are virtually the same as the fuming factors for the parent database. For consistency, and because the factors were derived from a the same larger data set, the FGR’s used for chromium (0.626% for GMAW and 0.413% for SMAW) were used for the nickel emissions calculations. The average ratios of fume nickel to electrode nickel of 8.97% for SMAW operations and 53.0% for GMAW operations were to be used in calculation for all nickel-containing electrode. These are displayed in Table 4-6.

Table 4-5. Derived Nickel Emission Factors

Nickel	Emission Characteristics	SMAW	GMAW
	1) Fume Generation Rate (lb. fume/ lb. rod) (%)	0.626%	0.413%
	2) Fume Composition (Fume Ni as a % of Rod Ni)	8.97%	53.0%
	Emission Factor (EF) (Product of above)	0.000561	0.00219

4.3.1.2 Summary of NASSCO Developed Emission Factors

The NASSCO developed emission factors are derived utilizing statistically sound methods based on the most current technical information available. NASSCO developed emission factors for Nickel and Hexavalent Chromium from arc welding operations (GMAW and SMAW). There are several other metals that may be of concern (i.e. manganese and cadmium). The same method for emission factor development can be applied to all metal constituents if data **is** available in the technical studies. The NASSCO emission factors and calculation techniques make it easily adaptable to various welding rods used throughout the shipbuilding process. Shipyards only need to collect data on the weld rod composition, respetive process (GMAW **or** SMAW), and the quantity of rod used (lbs). The NASSCO derived emission factors are general enough to be applied throughout the shipyard and are based on methods and technical data to make them as accurate as any method of estimating emissions from arc welding available.

4.3.2 California Air Resources Board (CARB) Emission Factor Evaluation

After NASSCO developed emissions factors with the assistance of Dr. Bell, the California Air Resources Board (CARB) was contacted to provide a response concerning their support of NASSCOs welding emission factors. Richard Bode, Manager of the Special Pollutant, Technical Support Division of the CARB was asked to provide assistance evaluating the welding emission factors. The results of the CARB evaluation and investigation are presented in Table 4-6 and 4-7.

able 4-6 Summary of Chromium Emission Factors

Source	Welding Process	Rod Type	% Cr in Rod	lbs fume / 100lbs rod	%Cr in Fume	%Cr6 in Rod	%Cr6/ Cr in Fume	Cr Lbs Metal/Lb Rod	Cr6 Lbs Metal/Lb Rod
AWS (1979)	SMAW	E316-15	18.7	0.71	5.8	3.949	68.08	4.12E-04	2.80E-04
–	–	E316-16	18.7	0.60	6.5	3.949	60.75	3.90E-04	2.37E-04
–	–	E9018B3 (17)	N/A	1.22	1.6	—	–	1.95E-04	
–	–	Inconel 625	21.5	0.70	5.9	3.949	66.93	4.13E-04	2.76E-04
–	–	Haynes C276	16	0.98	2.5	–	–	2.45E-04	
–	–	Haynes 25	20	0.65	6.9	3.949	57.23	4.49E-04	2.57E-04
AWMA 1993	–	E308-16	<15	0.64	6.2	–	–	3.97E-04	–
AWS (1979)	–	E8018C3 (14)	na	1.30	0.1	–	–	1.30E-04	–
AWMA 1993	–	E6010(A)	na	2.27	0.018	–	–	4.09E-04	–
–	–	E6010(B)	na	2.05	0.011	–	–	2.26E-04	–
–	–	E6011	na	3.84	0.012	–	–	4.61E-04	–
–	–	E6013	na	1.36	0.03	–	–	4.08E-04	–
–	–	E7018	0.03	1.57	0.024	–	–	3.77E-04	–

Source	Welding Process	Rod Type	% Cr in Rod	lbs fume / 100lbs rod	% Cr in Fume	% Cr6 in Rod	%Cr6 /Cr in Fume	Cr Lbs Metal/Lb Rod	Cr6 Lbs Metal/Lb Rod
AWS (1979)	GMAW	E316-L	18.7	0.84	12.5	3.949	0.62	1.05E-03	5.21E-05
–	–	Inconel 625	21.5	0.08	15.4	3.949	0.62	1.23E-04	4.96E-06
–	–	Haynes C276	16	0.69	8.2	—	0.62	5.66E-04	4.28E-05
–	–	Haynes 25	20	0.13	14.9	3.949	0.62	1.94E-04	8.06E-06
–	–	ERNiCu-7	na	0.20	0.01	3.949	–	2.00E-07	–
AWMA 1993	–	E308LSi	20	0.54	6.0	–	–	3.24E-04	–
–	–	E70S-3	na	0.86	0.02.9	3.949	–	1.72E-06	–
–	–	E70S-6	na	0.79	0.015	–	–	1.19E-06	–

Table 4-7 Summary of Other Metals Emission Factors

Source	Welding Process	Rod Type	lbs fume / 100lbs rod	% Mn in Fume	% Ni in Fume	% Cu in Fume	Mn Lbs Metal/Lb Rod	Ni Lbs Metal/Lb Rod	Cu Lbs Metal/Lb Rod
AWS (1979)	SMAW	E6010 (11)	3.56	3.4			1.21E-03		
		E6010 (1)	2.48	3.0			7.44E-04		
		E6010 (2)	2.19	3.4			7.45E-04		
		E6013 (3)	1.80	4.1			7.38E-04		
		E6013 (4)	1.65	5.1			8.42E-04		
		E6013 (6)	1.01	5.5			5.56E-04		
		E7018 (5)	1.6	4.5			7.20E-04		
		E7018 (10)	1.54	3.6			5.54E-04		
		E7018 (12)	1.64	4.1			6.72E-04		
		E7024 (7)	0.67	5.3			3.55E-04		
		E7024 (8)	0.67	5.6			3.75E-04		
		E7024 (9)	0.63	7.8			4.91E-04		
		E8018 (14)	1.30	7.2	0.3	–	9.36E-04	3.90E-05	
		E9018 (17)	1.22	5.9	0.1	–	7.20E-04	1.22E-05	
		E316-15 (22)	0.73	7.7	1.1	–	5.62E-04	8.03E-05	
		E316-16 (20)	0.73	8.8	1.5	–	6.42E-04	1.10E-04	
		E410-16 (21)	0.96	5.2	0.1	–	4.99E-04	9.60E-06	
		ENi-Cl	1.22	0.30	6.9	0.10	3.66E-05	8.42E-04	1.22E-05
		ENiCu-2	0.74	2.1	4.2	6.20	1.55E-04	3.11E-04	4.59E-04
		Inconel 625	0.70	–	4.6	0.70	–	3.22E-04	4.90E-05
		Haynes C-276	0.98	0.30	1.1	–	2.94E-05	1.08E-04	
		Haynes 25	0.65	4.6	1.8	–	2.99E-04	1.17E-04	
AWMA 1993		E6010 (A)	2.27	3.9	0.026	0.26	8.85E-04	5.90E-06	5.90E-05
		E6010 (B)	2.05	4.4	0.008	0.033	9.02E-04	1.64E-06	6.77E-06
		E6011	3.84	2.6	0.014	0.014	9.98E-04	5.38E-06	5.38E-06
		E6013	1.36	4.1	0.018	0.16	5.58E-04	2.45E-06	2.18E-05
		E308-16	0.64	3.8	0.82	0.10	2.43E-04	5.25E-05	6.40E-06
		E7018	1.57	3.9	0.012	0.072	6.12E-04	1.88E-06	1.13E-05

Source	Welding Process	Rod Type	lbs fume / 100lbs rod	%Mn in Fume	% Ni in Fume	%Cu in Fume	Mn Lbs Metal/Lb Rod	Ni Lbs Metal/Lb Rod	Cu Lbs Metal/Lb Rod
AWS (1979)	GMAW	E70S-3 (A2O2)	0.53	5.57	–	1.29	2.95E-04		6.84E-05
		E70S-3 (A9C2)	0.73	4.6	–	0.99	3.36E-04		7.23E-05
		E70S-3 (CO2)	0.32	5.5	–	1.2	1.76E-04		3.84E-05
		E70S-S5	0.41	5.8	–	1.75	2.38E-04		7.18E-05
		Inconel 625	0.08	-	27.2	0.69	–	2.18E-04	5.52E-06
		Haynes C-276	0.69	1.0	32.5	–	–	2.24E-03	–
		Haynes 25	0.13	–15.4	7.1	–	–	9.23E-05	–
		ERCuAL-A2	0.79	–	–	70.5	–	–	5.57E-03
		ERCu	0.47	–	–	66	–	–	3.10E-03
		ERNiCu-7	0.20	1.1	22.1	44.4	2.20E-05	4.42E-05	8.88E-04
AWMA 1993		E70S-3	0.86	6.7	0.0072	0.065	5.76E-04	6.19E-07	5.59E-05
		E70S-6	0.79	10.4	0.014	0.44	8.22E-04	1.11E-06	3.48E-05
		E308LSi	0.54	6.4	0.50	0.50	3.46E-04	1.84E-04	2.70E-05

4.3.2.1 Emission Factor Development

The CARB reviewed the scientific literature with the intent of refining and/or accepting the emissions factors developed by NASSCO. Their analysis included information from two American Weld Society (AWS) reports and information presented at the 86th Annual Meeting of the Air& Waste Management Association (AWMA), by R.W. Gerstle, in Denver Colorado. In summary, they estimated and agreed with the fact that the emissions factors needed to be process dependent. They determined that separating the factors for SMAW and GMAW was appropriate for emission factor simplification purposes.

Table 4-6 summarize the information supported by the CARB. They recognize and note in Table 1 that data shows averaged percentage of hexavalent chromium to total chromium for the SMAW process is approximately 63%, while it is approximately 5% for the GMAW process. Their technical evaluation supports the fact that the SMAW process produced significantly more hexavalent chromium than the GMAW process.

They support emission factors based *on the* information provided in Table 4-6 and 4-7 when the shipyard knows the type of welding electrode and the type of process employed. Table 4-6 displays the chromium emission factors developed by the CARB staff.

4.3.2.2 Summary of CARB Emission Factors

They recommend using the data in the previous two tables to calculate emission factors, if the shipyard knows the types of weld rod utilized and the process. They recognize that the data in the tables show that concentrations of metals in the fume are relatively higher for electrodes With higher metal contents. Also, they believe that it is reasonable to assume that the concentrations of the metal in the fume are relatively higher for lower melting point metals. Therefore, each metal has an emission potential that is not directly related to the metals concentration in the welding electrode. The CARB also supports the fact that the hexavalent chrome factors in the unpublished AWS report were derived from appropriate scientific analysis protocol.

4.3.31990 SARA Section 313 Reporting Issue Paper

In 1990, the EPA Office of Toxic Substances published an issue Paper for Clarification and Guidance for the Metal Fabrication Industry for Section 313, Toxic Release Inventory (TRI) Reporting. Within this Issue Paper, a section is entitled “Estimating Emissions From Metal Welding And Oxygen Cutting Operations.” This paper addresses welding emissions and how they are related to SARA Form R Release Reporting thresholds.

4.3.3.1 Emission Factor Development

The paper concurs that releases during electric arc welding operations are largely driven by the welding rod type and the welding process utilized. The following equations for emission calculation and reporting are presented in this report.

Release of Metal (lbs/yr)	**=**	**Weight of Rod Used (lbs)**	**X**	**Percent Composition (% Metal)**	**X**	**Emission Factor (lbs/ton rods)**	X	**Conversion Factor (2000 lbs/ton)**

The following eight tables are used to identify the “Emission Factor to be used. The tables represent factors for SMAW (low and high alloy), FCAW (low and high alloy), GMAW (low and high alloy), and GMAW (Copper and Aluminum wire). This data represents average fume generation rates and percent metal in the time taken from the 1979 document Fumes *and Gasses* in the *Welding Enviornment* by the American Weld Society (AWS-1979). This is the same technical document used by Dr. Bell to develop NASSCO emission factors. The document explains that the tables should be used to predict the facilities toxic emissions of Manganese (Mn), Nickel (Ni), Copper (Cu) and Chromium (Cr).

Shielded Metal Arc Covered Electrodes (*Carbon and Low Alloy Steel*)

		% 313 Metal in Fume					Emission Factor Lbs/ton			
Electrode Class	**Ave. FGR (g/kg)**	**Mn**	**Ni**	**Cu**	**Cr**	**——**	**Mn**	**Ni**	**Cu**	**Cr**
E6010	35.9	3.2				——	2.3			
E6013	20.0	4.9				——	2.0			
E7018	21.1	4.1				——	1.8			
E7024	10.0	6.2				——	1.2			
E8018	16.9	7.2				——	1.2			

Shielded Metal Arc Covered Electrodes (Stainless Steel and High Alloy Steel)

		% 313 Metal in Fume					Emission Factor Lbs/ton			
Electrode Class	**Ave. FGR (g/kg)**	**Mn**	**Ni**	**Cu**	**Cr**	**——**	**Mn**	**Ni**	**Cu**	**Cr**
E316-15	9.6	7.7	1.1		5.8	——	1.5	0.2		1.1
E316-16	9.2	8.8	1.5		6.5	——	1.6	0.3		1.2
E410-16	12.9	5.2	<0.1			——	1.3	0.02		
Eni Cl	12.9	0.3	6.9	<0.1			0.1	1.8	0.02	
Eni Cu2	10.1	2.1	4.2	6.2		——	0.4	0.8	1.2	
Inc. 625	9.2	4.6	0.7	5.9			0.8	0.1	1.1	
Haynes C276	14.2	0.3	1.1		2.5		0.1	0.3		0.7
Haynes 25	8.9	4.6	1.8		6.9		0.8	0.3		1.2

Flux Cored Electrodes (Low Carbon and Low Alloy)

		% 313 Metal in Fume					Emission Factor Lbs/ton			
Electrode Class	**Ave. FGR (g/kg)**	**Mn**	**Ni**	**Cu**	**Cr**	**——**	**Mn**	**Ni**	**Cu**	**Cr**
E70T-1	12.1	9.2					2.2			
E70T-4	13.3	3.9	<0.01				0.8			
E70T-5	21.0	11.1					4.7			

Flux Cored Electrodes (High Alloy & Stainless Steel)

		% 313 Metal in Fume					Emission Factor Lbs/ton			
Electrode Class	**Ave. FGR (g/kg)**	**Mn**	**Ni**	**Cu**	**Cr**	**——**	**Mn**	**Ni**	**Cu**	**Cr**
E316LT-3	9.6	7.3	1.1		12.5		1.4	0.2		2.4

Gas Metal Arc Welding (Low Carbon Steel & Low Alloy)

		% 313 Metal in Fume					Emission Factor Lbs/ton			
Electrode Class	**Ave. FGR (g/kg)**	**Mn**	**Ni**	**Cu**	**Cr**	**——**	**Mn**	**Ni**	**Cu**	**Cr**
E70S-3	5.1	5.3		0.7			0.5		0.1	
E70S-5	4.0	5.8		1.8			0.5		0.1	

Gas Metal Arc Welding (Stainless Steel and High Alloy)

		% 313 Metal in Fume					Emission Factor Lbs/ton			
Electrode Class	Ave. FGR (g/kg)	Mn	Ni	Cu	Cr	——	Mn	Ni	Cu	Cr
ERNiCu-7	2.0	1.1	22.1	44.4	0.01		0.04	0.9	1.8	
Inconel 625	0.9		27.2	0.7	15.4			0.5	0.01	0.3
Haynes 25	1.4	15.4	7.1		14.9		0.4	0.2		0.4
Haynes C 276	7.0	1.0	32.5		8.2		0.1	4.6		1.2

Gas Metal Arc Welding (Solid Aluminum Wire)

		% 313 Metal in Fume	Emission Factor Lbs/ton
Electrode Class	Ave. FGR (g/kg)	Aluminum	Aluminum
ER4043	10.7	46.2	9.9
ER5356	72.3	38.0	54.9

Gas Metal Arc Welding (Solid Copper Wire)

		% 313 Metal in Fume	Emission Factor Lbs/ton
Electrode Class	Ave. FGR (g/kg)	Copper	Copper
ERCu	4.9	66.0	6.5
ERCuAL-A2	8.1	70.5	11.4

4.3.3.2 Summary of SARA 313 Emission Factors

This paper submits that if the tables do not list specific rods used, similar rods should be chosen and adjusted for varying percentages of reportable components. The paper does not determine or suggest a method to adjust for various rod types and does not address the derivation of hexavalent chromium emissions. It does, however, try to address the fact that welding processes with high an low alloy rods will yield different FGRs although the data does not vary significantly. The fact that the variations in material composition did not affect the FGR is the reason the NASSCO factors did not take into account low and high alloy differences. Although at times, SMAW rods with extremely low chrome content (i.e. 0.05%), will have a FGR over three times that of a SMAW rod, with 15% chrome.

4.3.4 1994 MRI Report: Development of Emission Factors for Electric Arc Welding

The document, *"Compliance of Air Pollution Emissions* Factors",(AP42), has been published by the US Environmental Protection Agency (EPA) since 1972. The EPA routinely updates this guidance document and provides supplements to AP-42 in response to federal, state, and local air pollution control programs. This document is the standard federal guidance reference used by state and local Air Quality Control Engineers for developing emission factors for various emission sources.

This section of the chapter is designed to provide a summary of the report entitled *"Development of Particulate and Hazardous Emission Factors for Electric Arc Welding (AP-42, Section 12.19)"* developed by MIDWEST RESEARCH INSTITUTE (MRI) for the Environmental Protection Agency (EPA contract No. 68-D2-0159) final report date May 20, 1994. The report provides background information on welding emissions to support preparation of a new AP-42 section for electric arc welding and "Draft Proposed Welding Emission Factors". The EPA Office of Air Quality Planning and Standards Emissions Inventory Branch will use the information presented in the report to help determine emission factors for welding processes.

The AP-42 report states that particulate matter and particulate-phase Hazardous Air Pollutants (HAPs) are the major concern with welding processes and associated emissions. The report concentrates on particulate matter emissions submicronic in size and are considered PM-10 (i.e. particles less than or equal to 10 micrometers in aerodynamic diameter). **This** report only addresses particulate phase air pollutants, while gas phase pollutants were not included in the scope of the study. The report emphasizes that only electric arc welding generates potentially toxic pollutants in substantial quantities to be of immediate concern for EPA emissions purposes. The lower operating temperatures of the other welding and cutting processes **cause fewer fumes to be released.** Also, **due to the limited availability of emissions data and other information** for other types of welding and cutting process, only four Source Classification Codes (SCC's) associated with electric arc welding were evaluated and proposed emissions factors are presented. The four processes are Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Flux Core Arc Welding (FCAW), and Submerged Metal Arc (SAW).

Hazardous metals designated in the *1990* Clean Air Act Amendments that have been recorded in welding fume include manganese (Mn), nickel (Ni), chromium (Cr), cobalt (Co), and lead (Pb). Gas phase pollutants are also generated during welding operations, but little information is available on these pollutants. Known gaseous pollutants (including "greenhouse" gases) include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_X), and ozone (O_3).

MRI researched and studied over 50 reference documents during the literature search and assessment stage. MRI outlined criteria with respect to the reliability of the data provided by each report and eliminated data that was incomplete or potentially inaccurate. The final set of 12 primary reports used to determine emissions factors is listed in Table 4-6. The AP-42 Report outlines in tabular form, emissions information provided by each of the referenced resource documents and provides a summary of the sample method, number of samples and other test protocol. All of the data collection and analysis yielded

The development of candidate emissions factors for PM-10 and HAP's emissions for SMAW, GMAW, FCAW, and SAW.

Table 4-6. Primary Reference Documents Used for Emissions Factor Determination
1. J.F.Mcllwain and L.A. Neumeier, "*Fumes from Shielded Metal Arc (MMA Welding) Electrodes*", RI-9105, U.S. Department of the Interior, Bureau of Mines, Rolla Research Center, Rolla, Missouri, 1987.
2. I.D. Henderson et al., "*Fume Generation and Chemical Analysis of Fume for a Selected Range of Flux-Cored Structural Steel Wires*", AWRA Document P9-44-85, Australian Welding Research, 15:4-11, December 1986.
3. K.G. Malmqvist et al., "*Process-Dependent Characteristics of Welding Fume Particles and Health Hazards and Biological Effects of Welding Fumes ad Gases*", R.M. Stem et al. eds., Excerpta Medica, Amsterdam, 31-46, 1986.
4. J. Moreton et al., "*Fume Emission When Welding Stainless Steel*", Metal Construction, 17:12,794-798, December 1985.
5. R.K. Tandon et al., "*Chemical Investigation of Some Electric Arc Welding Fumes and Their Potential Health Effects*", Australian Welding Research, 13:55-60, December 1984.
6. R.K. Tandon et al., "*Fume Generation and Melting Rates of Shielded Metal Arc Welding Electrodes*", Welding Journal, 63:8, August 1984.
7. E.J. Fasiska et al., "*Characterization of Arc Welding Fume*", American Welding Society, Miami, Florida, February 1983.
8. R.K. Tandon et al., "*Variations in the Chemical Composition and Generation Rates of Fume from Stainless Steel Electrodes Under Different AC Arc Welding Conditions*", AWRA Contract 90, Australian Welding Research, 11:27-30, December 1982.
9. R.M. Evans et al., "*Fumes and Gases in the Welding Environment*", American Welding Society, Miami, Florida, 1979.
10. R.F. Heile ad D.C. Hill, "Particulate Fume Generation in Arc Welding Processes", Welding Journal, 54:7, 201s-210s, July 1975.
11. Battelle-Columbus Laboratories, "*The Welding Environment*", Parts IIA, IIB, and III, American Welding Society, Miami, Florida, 1973.
12. IT Corporation, "*Development of Environmental Release Estimates For Welding Operations*", EPA Contract No. 68-C9-0036, , Cincinnati, Ohio, 1991.

4.3.4.1 Emission Factor Development

The following section describes the development of emission factors for both total particulate matter (PM) and hazardous air pollutants (HAPs) metals. Candidate emission factors were developed for SMAW, GMAW, FCAW, and SAW processes using average data from each primary reference. Table 4-7 summarizes the average data used and the candidate emission factors obtained during this analysis for PM-10 emissions. To derive each candidate emission factor, arithmetic averages of the test data in each reference document were calculated according to both the type of welding process tested and the type of electrode used. Next the individual averages were grouped by process and electrode type.

Weighted averages, based on the number of tests conducted in each study, were then calculated to obtain the candidate emission factor for each process/electrode combination. A rating was assigned to each candidate factor based on the quality of the data used as presented in Table 4-7 and Table 4-8.

Candidate emission factors were also developed for hazardous metals listed in the *1990* Clean **Air Act Amendments** using the data available in each primary reference. Again, all HAP emissions are considered to be in the PM-10 size range as discussed above. The same averaging approach used to develop the candidate emission factors for PM-10 emissions was used to derive similar factors for hazardous metals. A summary of the data used and the candidate emission factors obtained is provided in Table 4-8.

Table 4-7 PM-10 Emission Factors for Electric Arc Welding

Welding process	Electrode type (with last 2 digits of SCC)		Total fume emission factor (g/kg[lb/10^3 lb] of electrode consumed)[b]	EMISSION FACTOR RATING
SMAW[c] (SCC 3-09-051)	14Mn-4Cr	(-04)	81.6	C
	E11018	(-08)[h]	16.4	C
	E308	(-12)[j]	10.8	C
	E310	(-16)[k]	15.1	C
	E316	(-20)[m]	10.0	C
	E410	(-24)[n]	13.2	D
	E6010	(-28)	25.6	B
	E6011	(-32)	38.4	C
	E6012	(-36)	8.0	D
	E6013	(-40)	19.7	B
	E7018	(-44)	18.4	C
	E7024	(-48)	9.2	C
	E7028	(-52)	18.0	C
	E8018	(-56)[p]	17.1	C
	E9015	(-60)[q]	17.0	D
	E9018	(-64)[r]	16.9	C
	ECoCr	(-68)[s]	27.9	C
	ENi-Cl	(-72)	18.2	C
	ENiCrMo	(-76)[t]	11.7	C
	ENi-Cu	(-80)[u]	10.1	C

Welding process	Electrode type (with last 2 digits of SCC)		Total fume emission factor (g/kg[lb/10³ lb] of electrode consumed)[b]	EMISSION FACTOR RATING
GMAW[d,e] (SCC 3-09-052)	E308L E70S ER1260 ER5154 ER316 ERNiCrMo ERNiCu	(-12)[v] (-54)[w] (-10) (-26) (-20)[x] (-76)[y] (-80)[z]	5.4 5.2 20.5 24.1 3.2 3.9 2.0	C A D D C C C
FCAW[f,g] (SCC 3-09-053)	E110 E11018 E308LT E316LT E70T E71T	(-06)[aa] (-08) (-12)[bb] (-20)[cc] (-54)[dd] (-55)[ee]	20.8 57.0 9.1 8.5 15.1 12.2	D D C B B B
SAW[g] (SCC 3-09-054)	EM12K	(-10)[ff]	0.05	C

[a] References 7-18. SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; SAW = submerged arc welding. SCC = Source Classification Code.

[b] Mass of pollutant emitted per unit mass of electrode consumed. All welding fume is considered to be PM-10 (particles £ 10 mm in aerodynamic diameter).

[c] Current = 102 to 229 A; voltage = 21 to 34 V.

[d] Current = 160 to 275 A; voltage = 20 to 32 V.

[e] Current = 275 to 460 A; voltage = 19 to 32 V.

[f] Current = 450 to 550 A; voltage = 31 to 32 V.

[g] Type of shielding gas employed will influence emission factor.

[h] Includes E11018-M

[j] Includes E308-16 and E308L-15

[k] Includes E310-16

[m] Includes E316-15, E316-16, and E316L-16

[n] Includes E410-16

[p] Includes E8018C3

[q] Includes E9015B3

[r] Includes E9018B3 and E9018G

[s] Includes ECoCr-A

[t] Includes ENiCrMo-4

Includes ENi-Cu-2

[v] Includes E308LSi

[w] Includes E70S-3, E70S-5, and E70S-6

[x] Includes ER316I-Si and ER316L-Si

[w] Includes ENiCrMo-3 and ENi-CrMo-4

[z] Includes ERNiCu-7

[aa] Includes E110TS-K3

[bb] Includes E308LT-3

[cc] Includes E316LT-3

[dd] Includes E70T-1, E70T-2, E70T-4, E70T-5, E70T-6, and E70T-7

[ee] Includes E71T-1 and E71T-11

[ff] Includes EM12K1 and F72-EM12K2

Table 4-8 Hazardous Air Pollutants (HAPs) Emission Factors for Electric Arc Welding

Welding Process	Electrode Type		Total fume emission factor (g/kg[lb/10^3 lb] of electrode consumed)						EF Rating
			Cr	Cr (IV)	Co	Mn	Ni	Pb	
SMAW[c] (SCC 3-09-051)	14Mn-4Cr	(-04)	13.9	-	-	232	17.1	-	C
	E11018	(-08)[h]	-	-	-	13.8	-	-	C
	E308	(-12)[j]	3.93	3.59	0.01	2.52	0.43	-	D
	E310	(-16)[k]	25.3	18.8	-	22.0	1.96	0.24	C
	E316	(-20)[m]	5.22	3.32	-	5.44	0.55	-	D
	E410n	(-24)[n]	-	-	-	6.85	0.14	-	C
	E6010	(-28)	0.03	0.01	-	9.91	0.04	-	B
	E6011	(-32)	0.05	-	0.01	9.98	0.05	-	C
	E6012	(-36)	-	-	-	-	-	-	-
	E6013	(-40)	0.04	-	< 0.01	9.45	0.02	-	B
	E7018	(-44)	0.06	-	< 0.01	10.3	0.02	-	C
	E7024	(-48)	0.01	-	-	6.29	-	-	C
	E7028	(-52)	0.13	-	-	8.4612.	-	1.62	C
	E8018	(-56)[p]	0.17	-	-	3	0.51	-	C
	E9016	(-60)	-	-	-	-	-	-	-
	E9018	(-64)[q]	2.12	-	-	7.83	0.13	-	C
	ECoCr	(-68)	-	-	-	-	-	-	-
	ENi-CI	(-72)	-	-	-	0.39	8.90	-	C
	ENiCrMo	(-76)[r]	4.20	-	-	0.43	2.47	-	C
	ENi-Cu-2	(-80)[s]	-	-	-	2.12	4.23	-	C
GMAW[d,e] (SCC 3-09-052)	E308	(-12)[t]	5.24	-	< 0.01	3.46	1.84	-	C
	E70S	(-54)[u]	0.01	-	< 0.01	3.18	0.01	-	A
	ER1260	(-10)	0.04	-	-	-	-	-	D
	ER5154	(-26)	0.10	-	-	0.34	-	-	D
	ER316	(-20)[v]	5.28	0.10	-	2.45	2.26	-	D
	ERNiCrMo	(-76)[w]	3.53	-	-	0.70	12.5	-	B
	ERNiCu	(-80)[x]	< 0.01	-	-	0.22	4.51	-	C
FCAW[f,g] (SCC 3-09-053)	E110	(-06)[y]	0.02	-	-	20.2	1.12	-	D
	E11018	(-08)[z]	9.69	-	-	7.04	1.02	-	C
	E308	(-12)	-	-	-	-	-	-	-
	E316	(-20)[aa]	9.70	1.40	-	5.90	0.93	-	B
	E70T	(-54)[bb]	0.04	-	-	8.91	0.05	-	B
	E71T	(-55)[cc]	0.02	-	< 0.01	6.62	0.04	-	B
SAW[h] (SCC 3-09-054)	EM12K	(-10)	-	-	-	-	-	-	-

[a] References 7-18. SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; SAW = submerged arc welding. SCC = Source Classification Code. Dash = No data.

[b] Mass of pollutant emitted per unit mass of electrode consumed. Cr = chromium, Cr(VI) = chromium +6 valence state; Co = cobalt; Mn = manganese; Ni = nickel; and Pb = lead. All HAP emissions are in the PM-10 size range (particles £ 10 mm in aerodynamic diameter).

[c] Current = 102 to 225 A; voltage = 21 to 34 V.

[d] Current = 275 to 460 A; voltage = 19 to 32 V.

[e] Type of shielding gas employed will influence emission factors.

[f] Current = 160 to 275 A; voltage = 22 to 34 V.

[g] Current = 450 to 550 A; voltage = 31 to 32 V.

[h] Includes E11018-M
[k] Includes E310-15
[n] Includes E410-16
[q] Includes 9018B3
[s] Includes ENi-Cu-2
[u] Includes E70S-3, E70S-5, and E70S-6
[w] Includes ERNiCrMo-3 and ERNiCrMo-4
[y] Includes E110TS-K3
[aa] Includes E316LT-3
[cc] Includes E71T-1 and E71T-11
[j] Includes E308-16 and E308L-15
[m] Includes E316-15, E316-16, and E316L-16
[p] Includes 8018C3
[r] Includes ENiCrMo-3 and ENiCrMo-4
[t] Includes E308LSi
[v] Includes ER316I-Si
[x] Includes ERNiCu-7
[z] Includes E11018-M
[bb] Includes E70T-1, E70T-2, E70T-4, E70T-5, and E70T-

4.3.4.2 Summary of AP-42 Emission Factors

This federal guidance document provides the most comprehensive data search of existing welding emissions data. This report presents emission factors for PM-10 and HAPs for specific welding rods for four major arc welding processes utilizing 12 primary sources of information. There is very little data available for hexavalent chromium, however, the information provided is consistent with emission factor information provided to NASSCO by the AWS.

The primary disadvantage of this report is that it does not define how one is to predict welding emissions from welding rods that are not listed in the emission factor tables. Therefore, this document is only a guide to help provide a comprehensive summery of available information concering welding emissions. This AP42 document does not develop generic federally supported emission factors that can be applied universally to a variety of welding electrode and different processes.

Appendix 1.
Shipyard Survey Form

Appendix 1.

Air Toxics Survey for Welding and Cutting Emissions

I would like to take a moment and thank you for your participation in this survey. As you are aware, the information that you provide will be a valuable resource for this project and I will be able to supply a more useful document/study for the industry as a result. I need to understand some of the constraints, limitations, and flexibility that the shipbuilding industry as a whole has regarding welding and cutting emissions. Below you will find a paragraph outlining the objectives and benefits of the study It is very important that the survey results are completed as soon as possible. If I can be of any assistance, or if you have any questions please contact meat (619) 544-7963.

Zachary F. Jacobs P.E.
Consulting Engineer

Note 1): I need to have responses to this questionnaire by June 14th 1994. Even incomplete responses will be appreciated because I will need as much information as possible.

Note 2): Please fax information to me at (619) 232-6411 and send information to:

Zack Jacobs
NASSCO M/S 22A
28th street & Harbor Dr., P.O. BOX 85278
San Diego, CA 92186-5278

Note 3): AU shipyard specific information will be kept in my files, treated as confidential information and not provided in the final report.

Introduction, Objectives, and Benefits of the Study:
This study is sub-project to the NSRP Toxic Air Emission project and designed to provide an analysis of control technologies and options for reduction of toxic emissions from shipyard welding and hot metal cutting operations. The study will provide a comprehensive evaluation of weld and cutting fume emission collection and filtration alternatives applicable to the shipbuilding and repair industry. An economic feasibility and cost analysis will be emphasized. Also, the project will investigate and identify process changes that can be implemented to reduce overall weld fume toxic emissions. The project will review current welding and cutting operations and available emission reduction technologies to better prepare shipyards for regulatory changes that may have an adverse impact on production operations. The study will attempt to prepare shipyards to take a proactive and information approach in the development of new environmental weld fume and hot metal cutting emission standards. A logicaI and well researched approach may influence the EPA to adopt standards more acceptable to shipyard operations. lt is planned that this report will provide background to assist in establishing standards that are flexible enough for the shipyard environment while minimizing toxic emissions to a degree economically feasible and operationally practicable.

Appendix 1.

For the following four questions, please provide any information that you have on the subjects:

1) Do you think that weld fume and emissions are an important future EPA and OSHA concern for American shipyards? Why or why Not?______________

____

2) Do you have any information on weld fume emissions and toxic emissions factors?____

3) Has your shipyard been approached by the local or state air quality agencies regarding weld fume emissions?

4) Have you had any OSHA compliance directives with respect to weld rod emissions?____

A) Welding Operations:

Please check process at your yard. GMAW___ *SMAW*____ SAW___, GTAW____, Brazing___, FCAW___.

Please list any other types of welding processes at your facility:

____

____

____

Do you have a record keeping system to determine how much rod wire, and electrode is used at your facility on an annual basis?

It has been displayed in several studies that gas shielding (GMAW) technology severely reduces that amount of toxic weld fume generation, GMAW is also much more productive and many shipyards are switching to wire feed GMAW. Has your facility been changing over from SMAW welding to GMAW? ______ If yes, which electrodes are being switched over? and on a percentage Basis, what are your future projections for switching to GMAW? (i.e. 50/50 for rod Mil-7018M)

____

____

____

____

____

Appendix 1.

Is your facility making any other changes to new welding and cutting technology that may be reducing emissions ?_____ If yes, what? ______________________

____

List the major drawbacks of converting to gas shielded arc (GMAW type processes):

____

____

____

____

B) Cutting Operations:

Please list all types of hot metal cutting operations at your facility and the metals being cut:

____

____

____

____

____

List any fume collection or controls on the cutting operations:

____

____

____

Total Shipyard Welding and **Cutting Percentage Estimates:** (Please provide best estimates for the following welding and cutting location questions)

Total welding = 100% of weld rods in lbs.

Buildings with weld booth collection systems______**% (how many systems** on-site?)
Buildings with/out weld booth collection systems______**% (how many systems** on-site?)
confined spaces with ventilation______%
Outdoor collection systems ______%
Outdoor welding no ventilation______%
Others ?

Total Cutting = 100% length of metals cut

Buildings with weld booth collection systems______% (how many systems on-site?)
Buildings with/out weld booth collection systems:______**%** (how many systems on-site?)
confined Spaces with Ventilation______%
Outdoor collection systems ______%

Outdoor welding no ventilation______%
Others ?

C) Current Shipyard Emission Collection and Controls:

Do you have any internal building collection systems that clean and recirculate air contaminated with welding fumes? _____ If yes, please provide system characteristics (Estimates are fine) and other information available on the system (i.e.size, CFM efficiency, disposal manufacture, cost etc.).

Building Collection Systems: (i.e.pipe shop collection system, sheet metal shop collection system, etc.) (control types = HEPA water curtain bag house, etc.)

System 1) Exit Flow Rate_______ CFM, # of Welding Stations ______, Control Type_______

System 2) Exit Flow Rate_______ CFM # of Welding Stations ______, Control Type_______

System 3) Exit Flow Rate_______ CFM # of Welding Stations ______, Control Type_______

Confined Space Systems:

Please provide any flow rate calculation techniques and requirements for weld fume extraction in confined spaces for shipyard applications. Are there any controls or filtration on these systems? __________

D) Stainless Steel and other Alloy Welding (Weld rods that contain Chromium]

As you are probably aware, chromium emissions are of great concern to the EPA and OSHA Stainless steel weld rods and wires contain high concentrations of chromium (20%). Please list any other weld rods that contain high concentrations of chromium (i.e. aluminum welding mil-11 1)

____

____

Where is stainless steel welding performed in the Shipyard?

Buildings with weld booth collection systems:______%
Buildings with/out weld booth collection system______%
confined Spaces with ventilation:______%
Outdoor collection systems: ______%
Outdoor welding no ventilation______%
others? _______%

Appendix 2.
Manufacturer Survey Form

Appendix 2.

Vendor Survey:

I would like to take a moment and thank you for your participation in this survey. As you are aware, the information that you provide will be a valuable resource for this project and the many shipyards that will read the report. The information supplied will be investigated and provided in a published report for the National Shipbuilding Research Program (NSRP). The primary mailing of this report will be sent to over approximately 350 individuals in the shipbuilding and repair industry. The shipbuilding welding issue is centered around chrome VI emissions (0.3 -0.5 microns) from welding stainless steel. Below you will find a paragraph outlining the objectives and benefits of the study. I is very important that the survey results are completed as soon as possible. If I can be of any assistance, or if you have any questions please contact me at (619) 544-7963.

Zachary F. Jacobs P.E.
Consulting Engineer

Note 1): I need to have responses to this questionnaire no later than Friday July 1st 1994. Even incomplete responses will be appreciated because I will need as much information as possible to prepare a comprehensive report.

Note 2): Please send information to:

Zack Jacobs
NASSCO M/S 22A
28th street & Harbor Dr., P.O. BOX 85278
San Diego, CA 92186-5278

Project Title: **Weld Fume Collection and Treatment Analysis For Application in the Shipbuilding Environment**

Introduction, Objectives, and Benefits of the Study:

This study is an NSRP project designed to provide an analysis of control technologies and options for reduction of toxic emissions from shipyard welding and hot metal cutting operations. The study will provide a comprehensive evaluation of weld and cutting fume emission collection and filtration alternatives applicable to the shipbuilding and repair industry. An economic feasibility and cost analysis will be emphasized. The project Will review current welding and cutting operations and available emission reduction technologies to better prepare shipyards for regulatory changes that may have an adverse impact on production operations. It is planned that this report will provide background to assist in establishing standards that are flexible enough for the shipyard environment while minimizing toxic emissions to a degree economically feasible and operationally practicable.

Shipyard Operations:

Shipyards perform SMAW and GMAW welding in the following configurations:

a) Shops with weld stations and collection systems
Filtration End of line multistage filtration system

b) Shops without weld stations and a collection system
Filtration Individual units (roll around with minimum 8' reach) or the installation of (a)

c) Outside areas in the shipyard
Filtration Individual units, must be extremely portable and have excellent reach (10 - 15ft or long vacuum tubes (20 -30 ft.)

d) Inside compartments on-board ships or inside large blocks in the yard.
Filtration: Individual units, must be extremely portable and have excellent reach (10 -15 ft) or long vacuum tubes (20 -30 ft.)

Please provide the following

1) Send any information/catalogs that you feel would be helpful for this study and analysis. (types of equipment filter information air flow rates and curves, and configurations)

2) Please send any information (articles, legal reports, etc.) that you may have on hexavalent chromium and/or other weld fume health problems and solutions that I should be made aware.

3) I will also be analyzing steel, aluminum stainless, and other hot metal cutting operations in the shipyard. Please educate me on any information that you may have about the toxicity and/or collection problems from hot metal cutting.

4) The project will require an emphasis on cost analysis for capital expenditure and continued cleaning and mechanical maintenance and unit replacement. It is realized that maintenance are only approximate but **best and worst case scenarios are to** be estimated.

Appendix 2.

5) Please provide a summary of features that make your products and/or service unique or more efficient user friendly, more effective, or more energy efficient.

6) Please provide any information and your opinion about the advantages and disadvantages of the different types of filter configurations (Media filters, Precipitators, automatic cleaning etc.).

7) Please fill out the following Survey Forms 1,2, and 3. Copy the forms and fill out one form for each alternative that you feel is applicable.

Survey Form 1 requests information on roll around weld fume filtration units. Roll around units are potentially applicable to the shipbuilding environment where only welding stations with chrome emissions will receive filtration.

a) The are reach should be at least 8 ft.
b) A longer (20 -25 ft) tube (4" dia) attachment would be nice for some areas at shipyards.
c) If you have a couple of units that I should investigate, please fill out Form 1 for each unit.

Survey Form *2* requests information on stationary units designed to filter all weld fumes from shops with multiple stations. Many shipyards have collection system to ventilate the shops. Our intention is to provide for multiple stage filtration at the exit point. Again capital cost and continued maintenance will be emphasized.
Please fill out Survey form 2 for Units designed near the following flow rates.

1) 1500-2000 CFM
2) 2000-3000 CFM
3) 3000-4000 CFM
4) 4000-5000 CFM
5) Maximum

Survey Form *2* requests information on recirculating free hanging units. Please supply information on the installation and operation of these types of units. I currently have very little information on shipyard average room sizes and configurations. I believe that this solution would be more practical for the colder climates with less open shops.

Appendix 3.
Shipbuilding Processes, Practices, and Operations

Appendix 3

Shipbuilding Processes, Facilities and Welding Operations:

1. Introduction to Shipyard Repair and New Construction Operations:

II. Major Shipyard Steel Processing Facilities (Open Work Areas):

- Panel Lines
- Parts Fabrication and Assembly Areas and Shops
- Rotary Turntables
- Pin Jigs Platen Lines (Assembly)

III. Shipyard Production Shops (Potentially Enclosed Areas):

- Pipe Shop
- Sheet Metal Shop
- Plate Shop
- Weld School
- Machining and Maintenance Shop

IV. New Construction OutFitting (Open Areas and Confined Spaces):

- Unit Outfitting and Construction
- On-Block Outfitting
- On-board Outfitting

Appendix 3

I. Introduction to Shipyard Repair and New Construction Operations:

Current Steel Shipbuilding Processes

Once a new instruction contract is awarded and most of the detailed design and production planning are performed, actual construction can begin. To understand the shipbuilding process', shipbuilding can be broken up into five general manufacturing levels. Figure 1. outlines the general manufacturing levels involved in the shipbuilding processes. The first level involves transforming of the raw materials (i.e. steel plates, steel bars, pipes, sheet metal, electrical, etc.) into parts. Therefore purchasing, handling, and production of these raw materials and parts is the first level of manufacturing ships. The second level is that which involves joining of the parts and steel members into subsections and sub-assemblies. The sub-assemblies of steel, pipe, venting, electrical and other outfitting are brought together to create the third level of ship construction. The third manufacturing level yields what is known as the hull blocks or units. These large blocks are transported throughout the shipyard and finally joined together on-board the ship which is the forth level. The forth level of ship manufacture known as erection. Erection is performed in one of the shipyard building positions which involves assembling the blocks together to form the ship. The fifth level of shipbuilding involves the final installation, completion, and testing of internal mechanisms and systems before the ship can be delivered to the owner. The entire ship construction process can take anywhere form 1 to 5 years depending on the size and complexity of the ship.

Shipbuilding materials must first go through several stages of construction before Blocks constructed and stacked and welded together at shipbuilding position (i.e. ship erected). The "Assembly Line" of the shipyard generally starts in the steel storage area. The steel is blasted With steel shot and primed with a instruction primer which preserves the steel during construction and allows for weldability. The steel is then fabricated into parts needed to construct the steel structure of the block and thus the ship. Fabricated parts are brought together to form Sub-Assemblies. At this stage, most of the parts are steel sections and plates. The Sub-Assemblies are brought together to form construction Blocks. The Blocks are then outfitted with materials and parts (i.e. piping, electrical boxes, lights, ventilation, etc,). The Blocks are then lifted onto the ship, which is referred to as erecting the ship. Once a block is lifted onto the ship, it is welded into place and systems are internally connected on the ship (on-board outfitting will be discussed in a further section).

The **Steel Ship Repair Process:**

The ship repair process operates much like the shipbuilding process although, due to the variety of ship repair work methods can vary from job-to-job. Repair contracts involve engine overhauls, resurfacing the hull and superstructure, reconfiguration of the ships interior, and many other repair and maintenance items. Ship repair contracts can last anywhere from one day to over a year depending on the complexity of the job. Repair contract are generally under Severe time constraints and prompt delivery is very important. Failure to deliver a repair ship on time can result in expensive fines for the shipyard. Repair activities tend to be somewhat cyclic, therefore the work-force will experience surges in workload.

Appendix 3

Large repair contracts and major conversions are common in the ship repair industry. Most of these large repair contracts are performed by shipyards that have the ability to construct ships although, some strictly repair yards perform extensive major structural repairs and conversions. Examples of major repair contracts are as follows:

- Conversion of supply ships to hospital ships
- Cutting a ship completely in half and installing a new section to lengthen the ship
- Replacing segments of a ship that has run aground
- Complete rip-out, Structural reconfiguration and outfitting of combat systems
- Major remodeling of ships interior or exterior (i.e. complete overhauls of passenger cruse ships)

Welding and Cutting Operations in the Shipyard Environment:

With the vast amount of work performed in the shipyard, welding and cutting operations are performed at nearly every location and process area of the shipyard. Welding and Cutting operations occur inside building, inside ships, at outdoor production lanes and in a variety of covered and uncovered production areas. A large percentage of welding production is not continuous operation and highly unpredictable even when shipyard workload is steady and appears somewhat consistent. For example, in many areas, welding is largely driven by inconsistent work practices such as the portion of ship (engine room, machinery spaces, etc.) under construction, **rework** construction timing, repair activities and a variety of special needs. The following three sections are designed to introduce the reader to shipbuilding and repair processes and their association to welding and cutting operations

II. Major Steel Joining And Cutting Production Areas:

There are four main areas in the shipyard where a good portion of the steel welding and cutting occurs. These areas are generally open and exposed to the ambient air environment although, in some shipyards, these areas may be in large covered areas and sheltered from the weather. The basic steel structural blocks are constructed in these areas and under high workload welding and cutting of steel, operations in these areas can be quite predictable and consistent.

Welding operations in these areas tends to be largely SMAW, SAW, and FCAW and very little other welding operations are performed in these production areas. Various grades of steel are the major materials processed in these areas although some Stainless Steel, Aluminum, and various piping materials can be found in these areas from time to time. Some Shipyards have specific areas where Aluminum and Stainless Steel are welded and processed while other shipyards that have less volume perform special welding operations at locations as space is available. Cutting in these areas tends to be with CNC Plasma Arc cutting machines and some torch cut-off used for trimming work-pieces.

Steel “Panel Lines”:

Increasing needs to produce ships more efficiently and increasing steel througput in the late 1960’s resulted in the development of shipyard “panel lines”. The panel line generally consists of motor driven conveyors with fixed reliefs used to move large plates together for joining (welding). Plates are joined together with mechanical and magnetic aids and seam welded. Seam welding can be performed by either one sided or two skied welding. Both are usually performed with Submerged Arc welding (SAW). Two sided welding requires the steel to be turned over for the second side welding. Longitudinal stiffeners are also welded on the panel line, which is generally performed using gravity welding machines (SMAW) or twin-fillet machines. A panel line could consist of the following stations: Plate Storage, Alignment/tack, Machine weld (side one), turnover, Machine weld (side two), Trim excess, Layout/tack stiffeners, Weld stiffeners, and Inspection. The assembly line operates with the aid of cranes (bridge, overhead, etc.). Welding machines are very accessible throughout the panel line for productivity.

Platen Lines (Assembly Platens)

Platen lines are generally the area in the shipyard where large construction blocks are assembled in the shipyard and help extend the assembly line approach for construction of the steel structure of the ship. Steel subassemblies constructed at the panel line and plate shop are brought together at the platen and assembled by welding and forming large construction blocks. The platen lines are serviced with various cranes for materials movement as well as welding and steel cutting equipment in a variety of configurations. The platen mainly provides locations for some sub-assembly construction, block layout, tack-welding, and final weld out.

Pin Jigs for Curved Blocks:

Pin Jigs are essentially platen lines used to assemble curved blocks. Pin jigs are situated throughout the shipyard into process lanes. The pin jig is possibly one of the simplest and most effective facilities developed by the modem shipbuilder. A pin jig is simply a series of vertical screw jacks that support curved blocks during construction. The jacks can be adjusted to attain the desired curvature. Curved blocks are the blocks that form the outside of the hulls curved surface. Mechanizing the production of curved blocks is much more difficult that rectangular blocks.

Rotary Turntables

Rotary tables are a facility that Construction Blocks are set into and rotate the block for a variety of production needs. The ability to rotate a block at a single location reduces the number of crane lifts needed to rotate the block from side to side and top to bottom. Rotary tables are used to exploit the increased efficiencies experienced when worker are able to weld and assemble blocks down-hand. Down-hand welding provides a higher quality weld With higher efficiency rates. To a lesser extent, turntables are also use for outfitting materials on We block because of accessibility to outfitting locations. However, most outfitting on the turntable is limited to large pipes and other steel structures and parts that are mainly fastened in place with bolts and steel flanges.

III. Shipyard Productions Shops:

Shipyards have a variety of shops and departments that are involved in the shipbuilding and repair process. Most of the shops are enclosed facilities in buildings and covered areas depending on the particular shipyard. The shops build and repair parts (piping systems, ventilation, foundations, etc.) and send them into the shipyard to be installed onto the ship under construction or repair. The shops are able to produce customized parts and pieces that are needed for the ship. In some cases, shipyard shops do not construct the parts and outside sources are used. In either case, materials installed onto the ship are installed by a representative from that department (i.e. pipe is installed by a pipe fitter). The following shops area sample of the types of operations that occur in the shipyard environment. Some shipyards may have more shops with highly specialized functions while other shipyard may not even possess the shops described in this section.

Pipe Shop:
The Pipe Shop is responsible for the manufacturing and assembling of piping systems. Manufacturing of piping systems involves a variety of cutting, welding, brazing, and mechanical bending. Piping systems are the largest outfitting task in shipbuilding. Small pipe sections known as "pipe spools" are assembled in the pipe shop and transported to the stages of construction (i.e. Assembly, On-Block, On-Unit, and On-Board). A typical ship may have from 10,000 to 25,000 individually instructed pipe spools.

The pipe shop has the widest range of welding and cutting operations in the shipyard. Some of the processes in the pipe shop include Pipe Welding (SMAW, GMAW, GTAW, FCAW, etc.), Pipe Bending, Flux Removal, Grit-blast, Pickling, Painting, Galvanizing, and Pressure Testing and pipe cutting. The Pipe shop performs the majority of their welding inside the building. Estimates are that 75 to 90% of all pipe welding is performed inside the shop. Therefore the remaining 10 to 25% of pipe welding occurs On-Block, On-Unit, or On-Board as will be discussed in the next section.

Sheet Metal Shop
The sheet metal shop is generally responsible for fabricating and installing ventilation ducting systems and ventilation spools. This shop utilizes engineering drawings and special sheet metal tools to produce ventilation systems for new construction as well as repair work The shop cuts, shapes, bends, welds, stamps, paints, and perform a variety of other manufacturing operations for ship ventilation systems. Many sheet metal shops are also responsible for assembling large ducting fans and heating and air conditioning components. Sheet metal workers perform the installation of the ducting in various stages of construction (i.e. On-block, On-unit, On-board). similar to the Pipe Shop, the Sheet Metal Shop performs approximately 75 to 90% of the required steel welding within their shop area and the remaining 10 to 25% is transferred to the On-Block or On-Board area.

Plate Shop:
The plate shop is a generic term used for the area or shop and process in the shipyard that provides steel parts cutting, bending and sub-assembly. The plate shop generally uses information from engineering drawings and produces plate shapes and parts. The shapes are cut and formed as needed with benders and frequently welded in to sub-assemblies. The plate shop generally has Computer Numeric Controlled (CNC) cutting machines, steel bending machines and plate bending rolls, shearing machines, presses, hole punching equipment and furnaces for heat treatment. The Plate Shop sends the parts and subassemblies to the stages of construction or the platen area for installation. Plate shops tend to perform mainly SMAW, FCAW and SAW processes on various grades of steel. Some stainless steel and aluminum are processed through the plate shop area although they are more infrequent.

Weld School:
The function of the weld school is to provide training for shipyard welders. This is an important function when shipyards are scaling up for a large contract or are implementing new processes or procedures. Welders are certified for the different types of welding in the shipyard (i.e. SMAW tacking, FCAW, SMAW Gravity machines, GTAW, SAW, etc.) Nearly every weld process occurs in the weld school especially when the shipyard is

providing training for a large upcoming contract.

Machine and Maintenance Shops:
The machining and maintenance shops service the entire shipyard for their machining and maintenance needs. The exact function of the shipyard maintenance and machine shops are not common throughout the shipbuilding industry. Shipyard machine shops perform a variety of functions that range from rebuilding pumps to turning 25 foot long propeller drive shafts on lathes, while the maintenance shop performs functions from repairing bicycles to overhauling 200 ton cranes. Equipment in the machine and maintenance shop consist of end mills, lathes, drill presses, CNC milling machines, band saws, large presses, work tables, cleaning tanks, and other machining and maintenance equipment. Very little production welding occurs in the **machine** shop or maintenance shop environments.

IV. New Construction Outfitting Processes and Production Areas:

Pre-erection outfitting of construction blooks is the current shipbuilding method used by all competitive shipbuilders worldwide. Outfitting is the process of installing parts and various sub assemblies (i.e. piping systems, ventilation equipment, electrical components, etc.) on the construction blooks prior to joining the blocks together at erection where the ship is finally assembled. The outfitting of blocks throughout the shipyard lends itself to forming an assembly line approach to shipbuilding.

Many of the components used in outfit systems are purchased from outside vendors and installed by the shipbuilder. Included in this category are main engines, generators, motors, pumps, valves, winches, cleats, and watertight doors. A second category of outfit components are manufactured into parts within the shipyard shops from raw materials, such as sheet metal, piping and tubing, electric cable, joiner materials, and insulation as discussed in previous sections.

The majority of outfitting occurs within the construction block when the block is outside in an open or covered area (On-Block area). Similarly, a good portion of outfitting occurs in somewhat confined spaced when outfitting occurs on-board the ship and to a lesser extent, on-block A small percentage of pipe and sheet metal welding and cutting occurs during the outfitting stages of construction although a certain percentage is unavoidable. For the most part, pipe spools and sheet metal ducting are constructed in the shops and simply bolted into place onto the construction block or Unit with little welding or cutting involved. Outfitting processes divide the shipbuilding process into stages of construction. Outfitting at each of the stages can be planned to make the construction process flow smoothly throughout the shipyard. For simplicity, outfitting can be divided into three main outfitting stages of construction once the steel structure of the block has been assembled. The three stages are as follows 1) On-Unit Outfitting and Construction, 2) On-Block Outfitting, and 3) On-Board Outfitting.

Unit Outfitting and Construction:
Unit outfitting is the stage where fittings, parts, foundations, machinery, and other outfitting material are assembled independent of the hull block (eg. Piping units are assembled/constructed separate from steel structural construction blocks). Assembly of such Units is call Unit outfitting and once the Units are constructed, they are installed onto construction blocks or onto the ship. Unit outfitting is important because it allow workers

to assemble shipboard components and systems in shops and work areas where they have easy access to the machinery and workshops. Units are either installed on the ship at the On-Board or On-Block stage of construction. Units come in varying sizes, shapes and complexities. In some cases, Units can be something as simple as a fan motor connected to a plenum and coil. Large Units are mainly composed of components in machinery spaces, boilers, pump rooms, and other complex areas of the ship.

Welding operations that occur On-Unit as limited to a small percentage of pipe welding and brazing and a small percentage of sheet metal cutting and welding. Outfitting Units on the ground increases safety and efficiency by reducing the man-hours which would otherwise be allocated to On-Block or On-Board in more confined spaces where work conditions are more difficult.

On-Block Outfitting:
On-Block outfitting is the stage of construction where most of the outfitting material is installed onto the Blocks. Outfitting materials that are installed On-Block consist of ventilation systems, piping systems, doors, lights, ladders, railings, electrical assemblies, and many others. Many Units are installed on the Block at the on-block stage. Throughout the On-Block outfitting stage, the Block can be lifted, rotated, and moved to efficiently facilitate installing outfitting materials on the ceilings, walls, and floors of the construction block structure.

On-Board Outfitting:
On-Board outfitting is performed after the blocks are lifted onto the ship under construction (eg. after erection). At this time, the ship is either at a building position (building ways or building dock) or the ships could be berthed at pier-side. The blocks are already outfitted to a large extent from the work performed at assembly, On-Unit, and On-Block, although much more work is still needed before the ship is ready to operate.
On-Board outfitting involves the process of installing large Units and Blocks on board the ship. Installation includes lifting the large Blocks and Units on board the new ship and welding them into place. On-Board outfitting also involves connecting the systems together (welding in many cases) that were installed on the blocks at previous stages (i.e. piping system, ventilation system and electrical system). All of the wiring systems are pulled throughout the ship at the on-board stage. The On-Board outfitting stage is not only the last stage, it is the most expensive, difficult, dangerous, confining, and time consuming.

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