Environmental Management Applicable to Welding, Cutting, and Gouging Processes in the Shipbuilding and Repair Industry

Revision 1

NSRP ASE Project – Reduction of Worker Exposure and Environmental Release of Welding Emissions

Technology Investment Agreement No. 2000922

Submitted to:

NSRP ASE Program
Advanced Technology Institute
North Charleston, SC

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Report

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on

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Advanced Technology Institute
North Charleston, SC

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1.0 Introduction

The purpose of this report is to provide an overview of the environmental management requirements that apply to shipyard welding, cutting, and gouging operations. It is important to recognize that this report discusses the compliance with the environmental guidelines specified by the U.S. Environmental Protection Agency (EPA) and the state agencies that aim to protect public health and the environment and does not include U.S. Department of Labor Occupational Safety & Health Administration (OSHA) requirements that aim to protect the worker health and the occupational environment. Another way to express the difference is that the facility fence line separates EPA and OSHA requirements. The EPA regulates effects of emissions outside the fence line and the OSHA regulates effects of emissions within the fence line. Waste streams expected from welding, cutting, and gouging operations mainly include, solid wastes, air emissions, and limited quantities of wastewater.

The Clean Air Act (CAA), the Clean Water Act (CWA), and the Resource Conservation and Recovery Act (RCRA) are the most important Federal environmental regulations applicable to welding, cutting, and gouging in a shipyard setting. These Federal environmental legislations control three primary waste streams, air pollutant emissions under CAA, wastewater discharges under CWA, and solid/hazardous wastes under RCRA.

Truly speaking, shipyard environmental management of welding, cutting, and gouging operations cannot be separated out because shipyard operations involve other processes as well. Major shipyard processes include, surface preparation, painting and coating, welding, cutting and gouging, vessel cleaning, degreasing, fiberglass manufacturing, and outfitting. Shipyard environmental permits address all processes together in one permit for each type of pollutant emitted from all shipyard processes. Each shipyard typically has an air permit, a wastewater permit to process wastewater and storm water, and a hazardous waste generator permit.

Environmental management involves several steps and typically, facilities are required to develop and implement an environmental management plan. Environmental management is a case specific exercise because, (1) state and local regulations differ, (2) each facility has its own process and product requirements, (3) each facility may have its own work practices, management guidelines, and philosophies, and other variables that influence environmental management practices. Keeping this in view, only generic shipyard environmental management guidelines applicable to welding, cutting, and gouging are discussed in this report.

Environmental management involves several steps and the most important ones are listed below:
1) Understanding processes, process variables (materials, material quality, products, product quality, process types, process equipment types used), and their impact on waste quantities and characteristics.

2) Emission quantification and characterization for the existing process conditions.

3) Applicable environmental regulations.

4) Environmental permits and compliance requirements.


6) Environmental performance measurement, benchmarking, feedback and improvements.

7) Optimization of environmental management costs.

This report briefly describes important components of the environmental management plan related to welding, thermal cutting, and gouging.

2.0 Environmental Regulations

The following paragraphs summarize a number of the most important Federal environmental regulations that cover wastes generated in industrial operations, including shipyards. The focus is on regulations that may apply to the solid and liquid wastes, and airborne emissions generated by welding, thermal cutting, and gouging operations.

2.1 Resource Conservation and Recovery Act (RCRA)

The Resource Conservation and Recovery Act (RCRA) of 1976 (40 CFR Parts 260-299) deals with the management of solid and hazardous wastes from the point of generation to disposal. Hazardous wastes include specific chemicals and materials that are ignitable, corrosive, reactive, or toxic. The RCRA applies to companies that generate, transport, treat, store, or dispose of hazardous waste and requires that they get a permit from the EPA or a state agency, authorized by the EPA.

2.2 Superfund Amendments and Reauthorization Act (SARA)

In 1980, congress passed The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. This act directed the EPA to deal with the release of hazardous substances that could be a risk to the environment and/or public health. A
second act, the 1986 Superfund Amendments and Reauthorization Act (SARA) expanded the scope and established SARA Title III, as the Emergency Planning and Community Right-to-Know Act (EPCRA). This legislation provides the public and local governments with information on potential chemical hazards in their communities. The Act requires facilities to provide emergency hazardous chemical release information, chemical inventories and toxic release reports. This information is provided to state emergency response commissions and local emergency planning committees for use in planning chemical emergency preparation and community awareness.

Section 313 of SARA lists the hazardous and toxic materials that must be reported. Table 1 lists some of the metals involved in welding, thermal cutting, and gouging operations that are reportable under SARA Section 313. Hazardous elements do not need to be reported if they make up less than the *de minimus* limit (minimum reportable) percentage of a material. Hazardous material reporting is further discussed in Section 5 of this report.

### 2.3 Clean Air Act (CAA)

Title III of the 1990 Clean Air Act Amendments (CAA) sets emission standards for 189 hazardous air pollutants (HAP). Facilities are generally categorized as major sources or minor sources based on HAP emissions. Title V of the act established National Ambient Air Quality Standards known as "NAAQS" for six criteria air pollutants. These pollutants are particulate matter (PM$_{10}$ and PM$_{2.5}$), sulfur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), carbon monoxide (CO), ozone (O$_3$) and particulate lead. These NAAQS are listed in Table 2.

Particulate matter is defined as follows:

- **TPM** – Total Particulate Matter
- **PM$_{10}$** – Particulate Matter less than 10 micron in size, also known as coarse particulate matter
- **PM$_{2.5}$** – Particulate matter less than 2.5 micron in size, also known as the fine particulate matter

Hazardous air pollutants (HAPs) do not have national ambient air quality standards, though some states have target ambient standards. The goal is to eliminate HAPs from the environment to the maximum extent possible without designating specific target levels. The EPA uses techniques such as the MACT (Maximum Achievable Control Technology) to restrict emissions of HAPs from industrial processes. The EPA requires the facilities to use the maximum achievable control technologies to capture and collect pollutants before they are
released from the industrial operation. The metals listed in Table 1 are considered to be HAPs and have to be controlled.

2.4 Clean Water Act (CWA)

The Clean Water Act (CWA) is directed at maintaining clean surface waters in the U. S. The act covers both direct and indirect discharge of water, including storm water, from facilities. Each facility must obtain a permit covering their discharge. The EPA and individual states have water quality standards that must be met. The Act’s stated objective is to “restore and maintain the chemical, physical, and biological integrity of the nation’s waters”. To achieve this objective, the Act establishes the following goals.

1) Elimination of discharge of pollutants into surface waters.

2) Achievement of level of water quality, which provides for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water.

3) Establishment of a national policy that the discharge of toxic pollutants in toxic amounts shall be prohibited.

3.0 Emission Characterization and Quantification

The EPA Office of Compliance report "Profile of the Shipbuilding and Repair Industry"(1) does not list welding, thermal cutting, and gouging operations as primary sources of waste or pollution. However, these processes do produce waste streams that include wastewater, solid wastes, and air emissions. The following paragraphs describe the most common of these wastes and emissions.

3.1 Solid Wastes Generated in Welding, Thermal Cutting and Gouging Operations {tc "I-3.7.2 Solid Wastes ” \l 2}

Solid wastes generated by welding, thermal cutting, and gouging operations include scrap welding electrodes, rods, and wires; flux, slag, spatter, and dross; and other solid wastes. These wastes are described as follows:

- Scrap welding electrodes – This category includes the stub ends of SMAW electrodes, scrap from damaged electrodes; the ends of spools or coils of solid and flux cored
electrodes for GMAW, SAW, and FCAW; and damaged rods or the ends of solid GTAW electrode or rods. Waste for SMAW electrodes may vary from 15% to 30% of the total amount of purchased electrodes, although this figure is highly variable. As 15%-20% of the welding electrodes become solid waste and are not used in the process, this amount should be deducted from the total quantity of electrodes consumed in calculating the air emissions. Scrap from solid or flux cored electrodes is on the order of 2%-6%. The composition of these wastes is the same as the purchased electrodes.

- **Flux** – Scrap flux is often the result of spillage and the composition is the same as the original material. There is a small amount of dust produced during flux handling.

- **Slag, Spatter, and Dross** – Slag is the residue from flux reactions produced during SMAW, FCAW, and SAW welding operations and is primarily composed of metal and non-metal oxides from the electrodes used for welding. Spatter is the oxidized metal particles expelled during welding. The composition of spatter is similar to the welding electrode. Dross is the oxidized metal expelled during thermal cutting and gouging operations and its composition is similar to the material being cut or gouged.

- **Other solid waste** – Other sources of solid waste may include the dust or fume collected in filters of ventilation systems and air pollution control devices. There may be solid waste (suspended and dissolved solids, metals, and other contaminants) recovered from the treatment of wastewater or storm water if the facility treats these liquid wastes (refer to the following section).

Disposal of solid wastes is typically accomplished by sending the waste to a metal scrap recycling facility, landfill, or waste disposal company.

### 3.2 Liquid Wastes Generated by Welding, Thermal Cutting and Gouging Operations

Welding, cutting, and gouging operations do not generate significant amounts of wastewater. Water from water-tables used during oxy-fuel gas (flame) cutting or plasma arc cutting operations has the potential to contain dissolved solids as well as solid metal and organic particles. If these water tables are cleaned and disposal of this water is required, the shipyard would be required to treat this wastewater for solids and metals before discharging into various water bodies. An alternative would be to dispose of it using an approved disposal company.

It also is possible that the fugitive air emissions generated during welding, cutting, and gouging operations may deposit on roof tops, on soil, and on pavements which may make their way into storm water during rain events. In order to prevent metals in storm water, a best management practices (BMP) plan has to be developed and implemented as part of the Storm Water Permit.
3.3 Air Emissions from Welding, Thermal Cutting and Gouging Operations

Air emissions are perhaps the most important waste stream resulting from welding, thermal cutting, and gouging operations. Welding, thermal cutting, and gouging processes generate particulate matter, metals, and limited amounts of other criteria pollutants such as ozone, oxides of nitrogen, and carbon monoxide. Lead is involved in some operations, although limited. Air pollutants emitted include those listed in Table 1 and Table 2 as well as others listed in the specific legislation.

4.0 Estimating Waste Quantities and Characteristics

4.1 Solid Waste

Solid wastes from welding, thermal cutting, and gouging are discussed in the preceding section of this report. These wastes include scrap welding electrodes, rods, and wires; flux, slag, spatter, and dross; and other solid wastes. The composition of these wastes and the potential hazardous materials they may contain can be estimated from the Material Safety Data Sheets (MSDS) for the base metals being cut or gouged or for the welding electrodes used. Some guidance on the amounts of some of these wastes that may be generated for certain operations is contained in the preceding section.

4.2 Air Emissions

Published literature indicates that different welding and cutting processes have different emission potentials for total fume and for hazardous air pollutants such as chromium (Cr), manganese (Mn), nickel (Ni), and others. Both the quantity and characteristics of air emissions can change from one welding process to another. Similarly, the quantity and characteristics of air emission vary with each thermal cutting or gouging method. The composition of base metals and welding electrodes as well as operating variables of each process can influence welding emissions. Some of the most important factors that influence the quantity and characteristics of air emissions are listed below:
Factors Affecting Air Emissions from Welding Processes

- The welding process itself (GTAW, GMAW, SMAW, FCAW, SAW, and others)
- Base metal type and composition (consult MSDS)
- Electrode or filler rod type, composition, and manufacturer (consult MSDS)
- Welding amperage and wire feed speed
- Welding voltage
- Contact tip to work distance (GMAW and FCAW)
- Shielding gas type and flow rate (where applicable)
- Welding power source (for pulsed current GMAW)
- Base metal surface contamination and coatings (paint, zinc, etc.)

Factors Affecting Air Emissions from Cutting and Gouging Processes

- The cutting or gouging process (OAC, PAC, Laser, CAC-A, etc.)
- Base metal type, composition, and thickness (consult MSDS)
- Voltage and amperage for PAC
- Gas type, flow, or pressure
- Cutting tip size for oxyfuel cutting
- Equipment type and adjustments
- Cutting speed
- Base metal surface contamination and coating (paint, zinc, etc.)

There are a number of references that provide guidelines for estimating emissions from welding and cutting processes, including the American Welding Society document “AWS F1.6, Guide for Estimating Welding Emissions for EPA and Ventilation Permit Reporting”. This document suggests methods that can be used to estimate emissions from welding processes. The basic method estimates emissions based on the quantity of welding electrodes used by the facility and the emission factor for each process or electrode.

Emission factors can be determined by one of four methods, depending on the precision needed for the estimate and the data available. These four methods are:

1) Estimation using emission factors based on the welding process.
2) Estimation based on emission factors for the specific classification of electrode.
3) Estimation based on more procedure specific emission factor data.
4) Estimation using on-site testing to measure emissions.

AWS F1.6 provides guideline emission factors for several welding processes that can be used for method 1. Since about 90% of welding emissions result from the electrode material, an estimate of emissions can be made by knowing the percentage composition of the constituents.
in the electrode. This information is available in the MSDS provided by the manufacturer. If more precise estimates are required, procedure specific emission factors can be determined or on-site testing can be done. The following sections of this report discuss available emission factor data and sampling and analysis methods that can be used for on-site testing of emissions.

The study by NASSCO and Jacobs Environmental Engineering Services\(^{(3)}\) has reported usefulness of the following equation to estimate a facility’s annual metal emission:

\[
\text{Release of metal, } E = W \times PC \times EF \times CF
\]

where:
- \(W\) = Total weight of welding electrode, pounds per year (lb/yr)
- \(PC\) = Percentage composition of a specific metal, %
- \(EF\) = Fume emission factor, pounds per ton (lb/ton) of electrode used
- \(CF\) = Conversion factor = (1/2,000) ton/lb
- \(E\) = Specific metal emitted, lb/year

### 4.2.1 Emission Factors

An emission factor is defined as the mass of a particular pollutant emitted per unit amount of work done, product produced, or raw material consumed. In the case of welding, emission factors for total particulate matter or for individual constituents can be expressed as a percentage of the electrode converted to fume, or as a weight of the electrode converted to fume per total weight of electrode consumed. Therefore emission factors may be expressed as: “% of particulate per pound of electrode”, “mg of particulates per pound (lb) of electrode consumed,” similarly for Cr, “mg of Cr per pound of electrode consumed.” Sometimes, it may be expressed as “pound of pollutant per pound of electrode consumed”, or other units may be used. Emission factors for cutting and gouging can be, “mg of pollutant per pound of material cut or removed,” or other suitable units may be used.

Emission factors are useful in emission quantification and reporting to local, state, and federal regulations. This is an important activity and an obligation under the facility air permit. The EPA maintains emission factors data in a document known as “Compilation of Air Pollutant Emission Factors AP-42\(^{(4)}\)” which is available at no cost through EPA’s web site www.epa.gov. Section 12.19 of AP-42 contains information on emission factors for specific pollutants for selected arc welding processes. The emission factors are given depending on the process and type of electrode used. Appendix A includes a copy of Section 12.19 of this document. Thus, when available, the emission factors can be used to estimate the amount of air emissions from the welding processes.
The EPA continues to collect the data as more and more research data becomes available. Although information is available, there are several emission scenarios for which emission factors have not been evaluated. The California Air Resources Board (CARB) has some emission factors data, which is used by California facilities in their reporting. The National Shipbuilding Research Program (NSRP)\(^{(3)}\), Maritime Environmental Resources and Information Center (MERIC), and Naval Surface Warfare Center, Carderock Division (NSWCCD)\(^{(5,6)}\) have evaluated emission factors recently for various welding and cutting operations.

A report by Z. F. Jacobs and NASSCO (1995)\(^{(3)}\) lists emission factors available from research done by NASSCO in collaboration with Dr. Richard L. Bell of Adams, Duque, and Hazeltine (AD and H).\(^{(3)}\) This report indicates that welding processes can be categorized into two broad groups based on emissions of welding fumes. They are GMAW and SMAW (though this categorization is too simplistic, it is presented here for shipyards to be aware of this source of information). The GMAW category includes variations such as FCAW and GTAW. On the other hand, the SMAW category includes the welding processes characterized by welding electrodes covered by a solid flux that is vaporized in the arc to provide shielding from oxidization. The following parameters are required to quantify emission of a certain metal:

1) Quantity of welding electrodes used
2) Process type (GMAW or SMAW)
3) Speciation of welding electrode (i.e., % chrome, etc.)

Other suitable parameters may be used to calculate the emission factors. For example, in the case of Cr(VI), the following parameters may be used.

1) Fraction of Cr (% Cr in rod) in the electrode
2) Fraction of the electrode turned into fume (FFR) (% electrode to fume)
3) Cr content in the fume (% Cr in fume)
4) Hexavalent Cr in the fume (% Cr\(^{+6}\) in fume)

The emission factor may then be calculated as follows:

\[
EF = \frac{FGR \text{ (lb fume/lb electrode as %)}}{\text{Fume Composition (lb Cr / lb fume as %)}} \times \frac{\text{Hexavalent portion of Cr emission (Cr}^{+6}\text{)/Cr in fume as %)}}{\}
\]

Examples of how emission factors can be calculated were given in the report.\(^{(3)}\)

Cutting emission factors are also available from NSWCCD/MERIC research though the data available is on a limited number of samples. The NSWCCD study identifies a wide range of
pollutant emissions reported in the literature. Table 3 lists the emission rates observed for cutting processes.\textsuperscript{(5,6)}

### 4.2.2 Sampling and Analysis for Fume Characterization and Quantification

Methods suggested by the EPA, OSHA, NOISH, or other standard methods can be used for fume characterization. As long as the methods used are scientifically justifiable, the regulatory agencies will accept the results.

Shipyards have to demonstrate compliance with the EPA and state environmental regulatory departments, which is often calculating a facility’s total atmospheric emissions of permitted air pollutants. This quantification is typically done using the published emission factor information. However, emission factors have not been established for all pollutants emitted by a shipyard. In the absence of emission factors, it becomes the shipyard’s responsibility to demonstrate calculations based on sound scientific and engineering methods. In certain situations, the EPA and state agencies may ask a facility to establish these emission factors through actual field measurements.

Estimating pollutant emission quantities is complex in the case of fugitive emissions (fugitive emissions are defined as the emissions escaping loosely from the process site, often without the aid of a fan or duct; emissions other than stack or duct emissions). If emission factors (e.g., in welding, an emission factor may be defined as the mass of a particular pollutant emitted per unit amount of electrode consumed) are known through source test methods, the same results can be used in estimating emissions from fugitive emissions.

The EPA has source test methods for measuring a variety of parameters required as part of determining mass pollutant emission rates. A number of source test methods applicable to shipyards in determining particulate emission rates from stacks or ducts are listed below. Copies of these methods are available from the EPA\textsuperscript{(7)}.

**Method 1:** Sample and Velocity Traverses for Stationary Sources

**Method 1A:** Sample and Velocity Traverses for Stationary Sources with Small Stacks or Ducts

**Method 2:** Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)

**Method 2A:** Direct Measurement of Gas Volume through Pipes and Small Ducts

**Method 2C:** Determination of Gas Velocity and Volumetric Flow Rate in Small Stacks or Ducts (Standard Pitot Tube)
Method 2D: Measurement of Gas Volume Flow Rates in Small Pipes and Ducts
Method 3: Gas Analysis for the Determination of Dry Molecular Weight
Method 4: Determination of Moisture Content in Stack Gases
Method 5: Determination of Particulate Matter Emissions from Stationary Sources

For example, the EPA has a source test method for estimating total particulates or total fume using Method 5. If shipyards have information on fume composition from other sources such as OSHA and/or a shipyard’s own data that was generated as a result of its compliance with OSHA, the fume composition information can be used in calculating total emissions of metals such as Cr, Mn, Ni, and others. The primary focus of the EPA is on facility atmospheric emissions and public health, whereas OSHA’s focus is worker exposure and worker health. It is important to know that overlap exists between the data sets gathered for EPA and OSHA compliance. The following few paragraphs present OSHA recommended methods for evaluating total fume and it’s composition.

The sampling of airborne fumes resulting from various welding processes using various base and filler metals may be done using calibrated personal sampling pumps. Different sampling rates are recommended for the collection of different types of samples, which could be collected on filters made of different materials. For example, OSHA recommends that hexavalent chromium (Cr(VI)) samples be collected on polyvinyl chloride (PVC) membrane filters of 5-µm pore size. The filters, generally enclosed in filter holders consisting of a three-piece polystyrene cassette, are placed near the collar of the welder for collecting representative breathing zone samples. For collecting area samples, filters can be placed in the general welding area. The influence of contaminants due to adjacent welding operations on the samples being collected should be minimized and/or determined. For comparison of results, it is recommended that the parameters influencing the samples be kept the same during the entire welding period.

The fumes collected on the filters can be analyzed for their constituent metals. Agencies such as the EPA, OSHA, and the National Institute for Occupational Safety and Health (NIOSH) have indicated standard procedures for performing extraction of the collected samples.(8)

The digested samples are then analyzed for their constituent metals using various analytical techniques, which include ion chromatography, atomic absorption spectroscopy, and the inductively coupled plasma method. For example, Cr(VI) can be analyzed using ion chromatography and metals like manganese and nickel can be analyzed using atomic absorption spectroscopy or the inductively coupled plasma method. Again, agencies like OSHA, NIOSH, and the EPA have recommended standard methods for analyzing various metals and non-metals. The analysis of the welding sample to estimate the amount of Cr(VI) using OSHA’s Method 215 has been given below for illustration of the sampling procedure.
5.0 Compliance with Environmental Regulations

Among environmental regulations, air quality regulations are important as welding, cutting, and gouging operations generate significant quantities of air pollutants. Comparatively, limited quantities of hazardous wastes and wastewater or storm water are generated as a result of these processes.

5.1 Resource Conservation and Recovery Act (RCRA)

Shipyards are required to have a hazardous waste generator permit according to RCRA guidelines. As most of the shipyards do not deal with treatment, storage and disposal (TSD) operations, they do not require a permit as a TSD facility. Welding, cutting, and gouging operations again have limited quantities of hazardous wastes. Dust collected from air pollution control devices may be categorized as hazardous waste and should be handled accordingly. Also, small quantities of acid wastes and waste flammable gases may be disposed according to the standard guidelines.

All hazardous wastes have to be identified, labeled, stored, and disposed of according to the guidelines applicable to the hazardous waste generators. When hazardous wastes are shipped, a manifest has to be filled out, a copy of which is sent to the state regulatory agency and a copy is maintained on-site. A set of the same is forwarded with the transporter who is responsible to give a copy to the TSD facility owner receiving the hazardous waste. Waste generated annually has to be reported to the state environmental regulatory agency as directed by the permit requirements or standard guidelines.

5.2 Clean Air Act (CAA)

Several sections of the Clean Air Act (CAA) apply to welding, cutting, and gouging operations. Compliance requirements and the pollutants permitted are specified in individual facility air permits. It is important to note that a facility permit addresses all processes together including welding, cutting, and gouging operations. Air permits may have specific requirements for welding, cutting, and gouging operations in view of hazardous air pollutant (HAP) emissions. Facilities are generally categorized as either major sources or minor sources. Based on HAP emissions, major sources are those that emit in excess of 25 tons per year (tpy) of total HAPs and/or 10 tpy of any single HAP. Major source categories are also evaluated based on criteria pollutants and the attainment and non-attainment regions. Major sources are required to have a TITLE V air permit which is complex compared to a general air permit that is issued to minor sources.
Facilities have to comply with the National Ambient Air Quality Standards for six criteria air pollutants. These are PM$_{10}$, SO$_2$, NO$_x$, CO, O$_3$, and particulate lead. Welding, cutting, and gouging processes are known to emit PM$_{10}$, NO$_x$, CO, O$_3$, and particulate lead. These NAAQS are listed in Table 2.

Hazardous air pollutants (HAPs) do not have national ambient air quality standards, though some states have target ambient standards. There are no risk based ambient standards for HAPs and the goal is to eliminate HAPs from the environment to the extent possible. The EPA uses techniques such as the MACT (Maximum Achievable Control Technology) to restrict emissions of HAPs from industrial processes. The EPA requires facilities to use the maximum achievable technologies to control pollutants before release from their industrial operations. Welding, cutting, and gouging operations emit metals and metal ions, which are considered HAPs and have to be controlled.

5.2.1 Atmospheric Dispersion Modeling

Compliance is evaluated through the use of atmospheric dispersion modeling. Knowing the emissions from welding, cutting, and gouging operations coupled with meteorological information and others, it is possible to estimate the incremental ambient concentration of specific pollutants. These incremental pollutant concentrations have to comply with state recommended limits, which has to be demonstrated before permitting, and also as a compliance demonstration after permitting.

The dilution of pollutants in the atmosphere occurs as a result of one or more of the following mechanisms:

- Transportation – result of wind motion
- Dispersion – due to the turbulence produced by wind
- Mass diffusion – caused by concentration gradients

Atmospheric dispersion models$^9$ use the basic Gaussian model, which is listed below:

\[
C_{(x, y, z; H)} = \frac{Q}{2\pi u \sigma_x \sigma_y} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{ \exp\left(\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(\frac{(z+H)^2}{2\sigma_z^2}\right) \right\}
\]

\[
C_{(x, y, z; H)} \quad \text{Ambient concentration of the pollutant at a receptor (x,y,z) when "H" is the effective emission height}
\]

\[
x \quad \text{Downwind distance from source to receptor, in meters}
\]

\[
y \quad \text{Crosswind distance from source to receptor, in meters}
\]

\[
z \quad \text{Vertical distance from source to receptor, in meters}
\]
\( u \) – Wind speed at the point of release in m/sec

\( \sigma_x \) and \( \sigma_y \) – Dispersion coefficients representing crosswind and vertical spread respectively in meters, which are functions of downwind distance “x” and the atmospheric stability

\( Q \) – Pollutant emission rate in g/sec

\( H \) – Effective height of the stack

It may be noted from the above model that,

- increase in effective stack/emission height will decrease the concentrations downwind and will shift the maximum concentration point to further away from stack
- increase in stack diameter will reduce the ambient concentrations
- increase in exit velocity at the tip of the stack will reduce the ambient concentrations
- maximum ambient concentration occurs on the downwind axis (y = 0)

Knowledge on dispersion of pollutants in the atmosphere will assist facilities in achieving environmental compliance, which is a great air quality management tool.

5.3 Clean Water Act (CWA)

The Clean Water Act (CWA) is implemented through the National Pollutant Discharge Elimination System (NPDES) permit program, which is the key component to control discharges from industrial facilities and POTWs (publicly owned treatment works) to surface waters of the U.S. Under the NPDES permit program regulations; the EPA may delegate authority to individual states to administer their own permit program in lieu of the federal program. In the absence of federal categorical standards for shipyards, CWA discharge limits are often established on the basis of Best Management Plans (BMPs). Discharge permits are required for all “point source” discharges of pollutants into waters of the U.S., including wetlands. Permits may also be required for indirect discharges of pollutants into municipal collection and treatment systems. The discharges are controlled under local or state pretreatment program requirements.

5.3.1 NPDES Permit Conditions

Normally, the primary purpose of an NPDES permit is to establish enforceable effluent limitations. In addition to effluent limitations, the NPDES permit establishes a number of other
enforceable conditions, such as monitoring and reporting requirements, a duty to properly operate and maintain systems, upset and bypass provisions, record keeping, inspection, and entry requirements.

In addition, an NPDES permit may require the permittee to perform BMPs, which are procedures designed to prevent or minimize the release of toxic or hazardous pollutants. BMPs are often simple "housekeeping" measures such as requirements to store drums in specific locations or to clean up spills promptly. BMPs are especially appropriate for storm water permits.

### 5.3.2 Effluent Limitations

All facilities are required to meet treatment levels based on the EPA’s assessment of the capabilities of treatment technologies that are technologically and economically achievable in the facility. More stringent treatment requirements must be met where they are found to be necessary to achieve water quality goals for the particular body of water into which a facility discharges. Water quality-based controls may be a combination of chemical-specific limitations, whole effluent toxicity control, and a biological criteria/bioassay and bio-survey approach. The effluent limitations and monitoring requirements for shipyards may vary.

### 5.3.3 Storm Water Permits

On September 29, 1995, the EPA issued the Multi-Sector General Permit (MSGP) (60 FR 50804), a final storm water general permit providing NPDES permit coverage for storm water discharges associated with 29 different industry sectors in 11 states and 4 territories without authorized NPDES programs. Shipyard facilities fall under this category.

The MSGP is based on site-specific information received from approximately 700 groups representing about 44,000 industrial facilities throughout the country. The MSGP is available to facilities that meet eligibility requirements, regardless of whether or not they participated in a group application.
5.3.4 Best Management Plan (BMP) Identification and Selection

Plans are required to contain a description of the controls and measures to prevent or minimize pollution of storm water and a specific schedule with interim milestones as to when measures and controls will be implemented. The measures and controls to prevent and minimize pollution of storm water must include:

1) Good housekeeping in industrial areas exposed to storm water.
2) Preventive maintenance of storm water controls and other facility equipment.
3) Spill prevention and response procedures to minimize the potential for and the impact of spills.
4) Training of employees on pollution prevention measures and record keeping.
5) Identification of areas with a high potential for erosion and the stabilization measures or structural controls to be used to limit erosion.
6) Implementation of traditional storm water management measures (oil/water separators, vegetative swales, detention ponds, etc.) where they are appropriate for the site.

6.0 Record Keeping and Reporting Requirements

6.1 Record Keeping Requirements Under Environmental Laws

A variety of information has to be maintained on-site in order to comply with their environmental requirements. Information should be collected and recorded in such a way that the pollutant emissions can be calculated correctly. In case of welding, (1) welding type, (2) welding process parameters, (3) type of base metal, and (4) type, composition, and quantity of weld rods/filler wire have to be recorded. In case of cutting, (1) type of metal cut, (2) average thickness, (3) length of cut, (4) cut speed, (5) type of cutting method, and (6) cutting process variables should be recorded. Similarly, for gouging all attributes have to be recorded so that the pollutant quantities can be estimated.

6.2 Environmental Reporting

Shipyards are required to develop and submit various reports demonstrating the compliance with environmental regulations dealing with multimedia waste streams. These reports have to
be submitted to various agencies such as the Environmental Protection Agency (EPA), the state environmental regulatory agency, local agencies such as the Police Department, Fire Fighting Department, and the Emergency Planning and Coordination Committee. Waste streams generated from welding, cutting, and gouging have to be accounted in calculating multimedia emissions as well as in reporting. The most common and important reports are discussed in the following section.

6.2.1 Air Emissions Inventory Reports

The facility air permit, the local/regional air quality management goals, and various other parameters affect reporting frequency and format. Most facilities have to characterize and quantify pollutants emitted through each permitted source (fugitive and non-fugitive type) monthly, quarterly, semi-annually, and annually. Typically, reporting may be semi-annually and annually. As the permit conditions are sometimes negotiable depending on the compliance history, current environmental practices, and proposed mitigation measures, reporting requirements among facilities may differ within the same state.

Welding, cutting, and gouging releases are calculated based on the available literature, which should be defendable. In case of questions on quantification methods, it is the shipyard’s responsibility to prove that the methods used are scientifically accurate to the extent known. A regulatory agency may ask the facility/shipyard to perform research to develop quantification methods.

6.2.2 Hazardous Waste Reports

If any hazardous waste is produced or created at the facility, the facility becomes the generator of that hazardous waste and is responsible for handling it properly until it is disposed of correctly. The responsibility starts with the creation of the hazardous waste and ends with the disposal, which is known as “the cradle to grave concept.” Though shipyards may use a transporter and a TSD facility (Treatment, Storage, and Disposal facility) to finally treat and dispose of hazardous wastes, the shipyards are liable in case the transporter and/or the TSD facility fail to properly manage the hazardous waste generated by the shipyard. Any contamination resulting from such mismanagement will transfer as a liability to the shipyard as a generator.
6.2.3 Toxics Release Inventory (TRI) Reports

Emergency Planning and Community Right-to-Know (EPCRA), promulgated along with the SARA, was designed to promote emergency planning efforts at state and local levels and provide citizens and local governments with information concerning potential chemical hazards in their communities. The Act, also known as SARA Title III, imposes requirements for facilities to provide emergency hazardous chemical release notification, chemical inventory reporting, and toxic chemical release reporting. SARA Title III gives states the authority to implement the law’s requirements. State emergency response commissions and local emergency planning committees have been appointed within each state to receive this information and use it for chemical emergency preparation and community awareness.

The facilities have to file Form R under Section 313 of EPCRA, also known as Title III of the Superfund Amendments and Re-authorization Act. This form is also known as the Toxic Chemical Release Inventory Reporting Form. Pollutants must be quantified and reported on Form R if a shipyard exceeds the threshold quantities (25,000 lb or 10,000 lb) mentioned in Section 313. De Minimus limit is used while calculating the threshold quantities. For example if Cr in weld rod is in excess of 1% by weight, then Cr present in excess of 1.0% should be included in threshold calculations for Cr. Calculations have to be made for Cr quantity present in all materials used in a shipyard. If the calculated value exceeds the threshold limit of 25,000 lb (or 10,000 lb if qualifies under “otherwise used” category), then Cr emissions have to be calculated and reported as part of TRI reporting.

TRI reports are submitted annually and are due on July 1, of every year for the previous calendar year. TRI reports include multi-media emissions resulting from the facility operation. They include air emissions, wastewater discharges (on-site and those shipped off-site), and solid/hazardous wastes.

6.2.4 Discharge Monitoring Reports (DMRs)

Under the NPDES permit and the Multi-Sector General Permit (MSGP), shipyards have to analyze the wastewater quality/quantity and storm water quality/quantity and report the results in a specified format to the state environmental permitting agency. These reports are called DMRs and the frequency of submission depends on the permit requirements. Though welding, cutting, and gouging operations may not generate significant wastewaters, they may contribute to pollutants in storm water discharges.
6.2.5 Tier II Reports

Shipyards have to report the hazardous materials that are stored at their facility to the state regulatory agency, local police department, local fire department, and the local emergency coordinator. Welding, cutting, and gouging processes may use certain flammable gases, the storage of which is regulated, and should be included in TIER II reports submitted annually.

7.0 Conclusions

This report should assist in understanding the shipyard environmental responsibilities relating to welding, cutting, and gouging operations. However, federal and state environmental regulations constantly change, so shipyards are cautioned to review the specific laws from time to time. Also, this report is meant to be generic and is not targeted to any specific shipyard. Emission factors presented are also meant to be samples of the type of data that should be used in quantifying and characterizing emissions. Presenting all available emission factors is beyond the scope of this report. Shipyards have to identify any new emission factor data that may become available from time to time. Shipyard environmental management activities and action plans are site-specific, and should be updated continually to meet ever-changing environmental regulations.
8.0 References


9.0 Bibliography


Table 1. Selected Metals to be Reported under SARA

<table>
<thead>
<tr>
<th>Hazardous Chemicals</th>
<th>De Minimus Limit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (fume or dust)</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Lead (when Lead is contained in stainless steel, brass or bronze alloys the de minimus level is 0.1)</td>
<td>− *</td>
</tr>
<tr>
<td>Manganese</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Mercury</td>
<td>− *</td>
</tr>
<tr>
<td>Nickel</td>
<td>− 0.1</td>
</tr>
<tr>
<td>Silver</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Thallium</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Antimony</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Arsenic</td>
<td>− 0.1</td>
</tr>
<tr>
<td>Barium</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Beryllium</td>
<td>− 0.1</td>
</tr>
<tr>
<td>Cadmium</td>
<td>− 0.1</td>
</tr>
<tr>
<td>Chromium</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Cobalt</td>
<td>− 0.1</td>
</tr>
<tr>
<td>Copper</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Vanadium (except when contained in an alloy)</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Zinc (fume or dust)</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Titanium tetrachloride</td>
<td>− 1.0</td>
</tr>
<tr>
<td>Phosphorous (yellow or white)</td>
<td>− 1.0</td>
</tr>
</tbody>
</table>


Note: Where (•) appears instead of a de minimus value, the chemical is a PBT (Persistent, Bioaccumulative, and Toxic) chemical and irrespective of its concentration in the material, it should be considered in calculations for reporting. Whereas other chemicals if present in lower concentrations than the corresponding indicated de minimus values, they need not be considered in calculations for reporting. Refer to the source listed below for additional information.

TRI reporting by applicable facilities is required by section 313 of the Emergency Community Right-to-Know Act (EPCRA, or Title III of the Superfund Amendments and Reauthorization Act of 1986), Public Law 99-499.
Table 2. National Ambient Air Quality (NAAQS) Standards

<table>
<thead>
<tr>
<th>Pollutant/ Averaging Time</th>
<th>Primary Standard&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Secondary Standard&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate Matter PM&lt;sub&gt;2.5&lt;/sub&gt; (annual)</td>
<td>15 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td>Based on 3-year average of annual arithmetic mean PM&lt;sub&gt;2.5&lt;/sub&gt; concentrations from single or multiple community-oriented monitors</td>
</tr>
<tr>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt;, (24-hour)</td>
<td>65 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td>Based on 3-year average of 98th percentile of 24-hour PM&lt;sub&gt;2.5&lt;/sub&gt; concentrations at each population-oriented monitor within an area</td>
</tr>
<tr>
<td>PM&lt;sub&gt;10&lt;/sub&gt;, annual</td>
<td>50 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>50 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Attained when expected annual arithmetic mean 50 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>PM&lt;sub&gt;10&lt;/sub&gt;, 24-hour</td>
<td>150 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>150 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Based on 99th percentile of 24-hour PM&lt;sub&gt;10&lt;/sub&gt; concentrations at each monitor within an area</td>
</tr>
<tr>
<td>Sulfur Dioxide SO&lt;sub&gt;2&lt;/sub&gt;, annual</td>
<td>80 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.03 ppm)</td>
<td></td>
<td>Never to be exceeded</td>
</tr>
<tr>
<td>SO&lt;sub&gt;2&lt;/sub&gt;, 24-hour</td>
<td>365 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.14 ppm)</td>
<td></td>
<td>Not to be exceeded more than once per year</td>
</tr>
<tr>
<td>SO&lt;sub&gt;2&lt;/sub&gt;, 3-hour</td>
<td>1,300 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.5 ppm)</td>
<td></td>
<td>Not to be exceed more than once per year</td>
</tr>
<tr>
<td>Nitrogen Dioxide NO&lt;sub&gt;2&lt;/sub&gt;, annual</td>
<td>100 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.053 ppm)</td>
<td>100 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.053 ppm)</td>
<td>Never to be exceeded</td>
</tr>
<tr>
<td>Ozone O&lt;sub&gt;3&lt;/sub&gt;, 8-hour</td>
<td>157 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.08 ppm)</td>
<td>157 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.08 ppm)</td>
<td>Based on 3-year average of annual 4th-highest daily maximum 8-hour ozone concentrations</td>
</tr>
<tr>
<td>O&lt;sub&gt;3&lt;/sub&gt;, 1-hour</td>
<td>235 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.08 ppm)</td>
<td>235 µg/m&lt;sup&gt;3&lt;/sup&gt; (0.12 ppm)</td>
<td>Standard is attained when the expected number of exceedances 1 – to be phased out (but present non-attainment areas must show 3 consecutive years of data meeting 1-hour standard before becoming attainment)</td>
</tr>
<tr>
<td>Carbon Monoxide CO, 8-hour</td>
<td>10 mg/m&lt;sup&gt;3&lt;/sup&gt; (9 ppm)</td>
<td></td>
<td>Not to be exceed more than once per year</td>
</tr>
<tr>
<td>CO, 1-hour</td>
<td>40 mg/m&lt;sup&gt;3&lt;/sup&gt; (35 ppm)</td>
<td></td>
<td>Not to be exceeded more than once per year</td>
</tr>
<tr>
<td>Lead Pb, calendar quarter</td>
<td>1.5 µg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td>Never to be exceeded</td>
</tr>
</tbody>
</table>

<sup>a</sup>For the protection of human health, with an adequate margin of safety.

<sup>b</sup>For the protection of other values, such as visibility, crops, materials, etc.
Table 3. Cutting Emission Rates

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Minimum ER g/sec</th>
<th>Maximum ER g/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPM</td>
<td>0.170</td>
<td>1.130</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>0.153</td>
<td>1.017</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>0.119</td>
<td>0.791</td>
</tr>
<tr>
<td>Oxides of Nitrogen (NO$_x$)</td>
<td>1.930</td>
<td>16.700</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>1.83 E-05</td>
<td>8.08 E-04</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>2.33 E-04</td>
<td>9.57 E-03</td>
</tr>
<tr>
<td>Hexavalent Chromium (Cr$_6$)</td>
<td>5.45 E-07</td>
<td>1.44 E-04</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>6.17 E-04</td>
<td>4.24 E-02</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>5.67 E-04</td>
<td>3.13 E-03</td>
</tr>
<tr>
<td>Coblat (Co)</td>
<td>1.83 E-05</td>
<td>2.53 E-04</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>7.27 E-04</td>
<td>1.22 E-02</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>3.02 E-04</td>
<td>2.81 E-03</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>2.00 E-05</td>
<td>6.22 E-04</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>8.50 E-04</td>
<td>1.74 E-02</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>1.66 E-06</td>
<td>2.66 E-05</td>
</tr>
</tbody>
</table>

Source: NSWCCD$^{(5,6)}$
12.19 Electric Arc Welding

NOTE: Because of the many Source Classification Codes (SCCs) associated with electric arc welding, the text of this Section will give only the first 3 of the 4 SCC number fields. The last field of each applicable SCC will be found in Tables 12.19-1 and 12.19-2 below.

12.19.1 Process Description

Welding is the process by which 2 metal parts are joined by melting the parts at the points of contact and simultaneously forming a connection with molten metal from these same parts or from a consumable electrode. In welding, the most frequently used methods for generating heat employ either an electric arc or a gas-oxygen flame.

There are more than 80 different types of welding operations in commercial use. These operations include not only arc and oxyfuel welding, but also brazing, soldering, thermal cutting, and gauging operations. Figure 12.19-1 is a diagram of the major types of welding and related processes, showing their relationship to one another.

Of the various processes illustrated in Figure 12.19-1, electric arc welding is by far the most often found. It is also the process that has the greatest emission potential. Although the national distribution of arc welding processes by frequency of use is not now known, the percentage of electrodes consumed in 1991, by process type, was as follows:

- Shielded metal arc welding (SMAW) – 45 percent
- Gas metal arc welding (GMAW) – 34 percent
- Flux cored arc welding (FCAW) – 17 percent
- Submerged arc welding (SAW) – 4 percent

12.19.1.1 Shielded Metal Arc Welding (SMAW)

SMAW uses heat produced by an electric arc to melt a covered electrode and the welding joint at the base metal. During operation, the rod core both conducts electric current to produce the arc and provides filler metal for the joint. The core of the covered electrode consists of either a solid metal rod of drawn or cast material or a solid metal rod fabricated by encasing metal powders in a metallic sheath. The electrode covering provides stability to the arc and protects the molten metal by creating shielding gases by vaporization of the cover.

12.19.1.2 Gas Metal Arc Welding (GMAW)

GMAW is a consumable electrode welding process that produces an arc between the pool of weld and a continuously supplied filler metal. An externally supplied gas is used to shield the arc.

12.19.1.3 Flux Cored Arc Welding (FCAW)

FCAW is a consumable electrode welding process that uses the heat generated by an arc between the continuous filler metal electrode and the weld pool to bond the metals. Shielding gas is provided from flux contained in the tubular electrode. This flux cored electrode consists of a metal sheath surrounding a core of various powdered materials. During the welding process, the electrode core material produces a slag cover on the face of the weld bead. The welding pool can be protected from the atmosphere either by self-shielded vaporization of the flux core or with a separately supplied shielding gas.
Figure 12.19-1. Welding and allied processes. (Source Classification Codes in parentheses.)
12.19.1.4 Submerged Arc Welding (SAW)

SAW produces an arc between a bare metal electrode and the work contained in a blanket of granular fusible flux. The flux submerges the arc and welding pool. The electrode generally serves as the filler material. The quality of the weld depends on the handling and care of the flux. The SAW process is limited to the downward and horizontal positions, but it has an extremely low fume formation rate.

12.19.2 Emissions And Controls

12.19.2.1 Emissions

Particulate matter and particulate-phase hazardous air pollutants are the major concerns in the welding processes. Only electric arc welding generates these pollutants in substantial quantities. The lower operating temperatures of the other welding processes cause fewer fumes to be released. Most of the particulate matter produced by welding is submicron in size and, as such, is considered to be all PM-10 (i.e., particles \( \leq 10 \) micrometers in aerodynamic diameter).

The elemental composition of the fume varies with the electrode type and with the workpiece composition. Hazardous metals designated in the 1990 Clean Air Act Amendments that have been recorded in welding fume include manganese (Mg), 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\(_3\)).

Table 12.19-1 presents PM-10 emission factors from SMAW, GMAW, FCAW, and SAW processes, for commonly used electrode types. Table 12.19-2 presents similar factors for hazardous metal emissions. Actual emissions will depend not only on the process and the electrode type, but also on the base metal material, voltage, current, arc length, shielding gas, travel speed, and welding electrode angle.

12.19.2.2 Controls

The best way to control welding fumes is to choose the proper process and operating variables for the given task. Also, capture and collection systems may be used to contain the fume at the source and to remove the fume with a collector. Capture systems may be welding booths, hoods, torch fume extractors, flexible ducts, and portable ducts. Collection systems may be high efficiency filters, electrostatic precipitators, particulate scrubbers, and activated carbon filters.
### Table 12.19-1 (Metric And English Units). PM-10 EMISSION FACTORS FOR WELDING OPERATIONS^a

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Electrode Type (With Last 2 Digits Of SCC)</th>
<th>Total Fine Emission Factor (g/kg [lb]/10^9 lb) Of Electrode Consumed</th>
<th>EMISION FACTOR RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW^b</td>
<td>E11018 (-08)^c</td>
<td>16.4</td>
<td>C</td>
</tr>
<tr>
<td>(SCC 3-09-051)</td>
<td>E308 (-08)^c</td>
<td>16.4</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E308 (-12)^c</td>
<td>10.8</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E310 (-16)^c</td>
<td>15.1</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E316 (-20)^d</td>
<td>10.0</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E410 (-24)^d</td>
<td>13.2</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>E5010 (-28)</td>
<td>25.6</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>E6011 (-32)</td>
<td>38.4</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E6012 (-36)</td>
<td>8.0</td>
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<td>E6013 (-40)</td>
<td>19.7</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>E7018 (-44)</td>
<td>18.4</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E7024 (-48)</td>
<td>9.2</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E7028 (-52)</td>
<td>18.0</td>
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<td>E8018 (-56)^f</td>
<td>17.1</td>
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<td>E9015 (-60)^f</td>
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<td>E9018 (-64)^f</td>
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<td>ENiCrMo</td>
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<td></td>
<td>ENi-Cu</td>
<td>10.1</td>
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<tr>
<td>OMAW^d,e</td>
<td>E308L (-12)^f</td>
<td>5.4</td>
<td>C</td>
</tr>
<tr>
<td>(SCC 3-09-052)</td>
<td>E70S (-54)^g</td>
<td>5.2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>ER1260 (-10)</td>
<td>20.5</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>ER3154 (-20)</td>
<td>24.1</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>ER316 (-20)^h</td>
<td>3.2</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>ERNiCrMo (-76)^i</td>
<td>3.9</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>ERNiCu (-80)^i</td>
<td>2.0</td>
<td>C</td>
</tr>
<tr>
<td>Welding Process</td>
<td>Electrode Type (With Last 2 Digits Of SCC)</td>
<td>Total Fume Emission Factor [g/kg (lbm/10^3 lb) Of Electrode Consumed]</td>
<td>EMISSION FACTOR RATING</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>FCAW&lt;*&lt;sup&gt;a&lt;/sup&gt; (SCC 3-09-053)</td>
<td>E110 <em>(06)</em>&lt;sup&gt;**&lt;/sup&gt;</td>
<td>20.8</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>E11018 <em>(08)</em></td>
<td>57.0</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>E108LT <em>(13)</em>&lt;sup&gt;bb&lt;/sup&gt;</td>
<td>9.1</td>
<td>C</td>
</tr>
<tr>
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<td>E116LT <em>(20)</em>&lt;sup&gt;**&lt;/sup&gt;</td>
<td>8.5</td>
<td>B</td>
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<tr>
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<td>E70T <em>(54)</em>&lt;sup&gt;dd&lt;/sup&gt;</td>
<td>15.1</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>E71T <em>(55)</em>&lt;sup&gt;**&lt;/sup&gt;</td>
<td>12.2</td>
<td>B</td>
</tr>
<tr>
<td>SAW&lt;sup&gt;b&lt;/sup&gt; (SCC 3-09-054)</td>
<td>EM12K <em>(10)</em>&lt;sup&gt;ff&lt;/sup&gt;</td>
<td>0.05</td>
<td>C</td>
</tr>
</tbody>
</table>

<sup>a</sup> 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.

<sup>b</sup> Mass of pollutant emitted per unit mass of electrode consumed. All welding fume is considered to be PM-10 (particles ≤ 10 μm in aerodynamic diameter).

<sup>c</sup> Current = 102 to 229 A; voltage = 21 to 34 V.

<sup>d</sup> Current = 160 to 275 A; voltage = 20 to 32 V.

<sup>e</sup> Current = 275 to 460 A; voltage = 19 to 32 V.

<sup>f</sup> Current = 450 to 550 A; voltage = 31 to 32 V.

<sup>g</sup> Type of shielding gas employed will influence emission factor.

<sup>h</sup> Includes E11018-M
<sup>i</sup> Includes E308-16 and E308L-15
<sup>j</sup> Includes E310-16
<sup>k</sup> Includes E316-15, E316-16, and E316L-16
<sup>m</sup> Includes E410-16
<sup>n</sup> Includes E8018C3
<sup>p</sup> Includes E9015B3
<sup>q</sup> Includes E9018B3 and E9018G
<sup>r</sup> Includes ECoCr-A
<sup>t</sup> Includes ENiCrMo-4
<sup>u</sup> Includes ENi-Cu-2
<sup>v</sup> Includes ER308LSi
<sup>w</sup> Includes E70S-3, E70S-5, and E70S-6
<sup>x</sup> Includes ER316LSi and ER316L-Si
<sup>y</sup> Includes ENiCrMo-3 and ENi-CrMo-4
<sup>z</sup> Includes ERNiCu-7

<sup>aa</sup> Includes E110TS-K3
<sup>bb</sup> Includes E308LT-3
<sup>cc</sup> Includes E316LT-3
<sup>dd</sup> Includes E70T-1, E70T-2, E70T-4, E70T-5, E70T-7, and E70T-G
<sup>ee</sup> Includes E71T-1 and E71T-11
<sup>ff</sup> Includes EM12K1 and F72-EM12K2
Table 12.19-2. HAZARDOUS AIR POLLUTANT (HAP) EMISSION FACTORS FOR WELDING OPERATIONS

<table>
<thead>
<tr>
<th>Welding Process</th>
<th>Electrode Type (With Last 2 Digits Of SCC)</th>
<th>HAP Emission Factor (10^-1 g/kg [10^-1/10^3 lb] Of Electrode Consumed)</th>
<th>EMISSION FACTOR RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW&lt;sup&gt;c&lt;/sup&gt; (SCC 3-09-051)</td>
<td>14Mn-4Cr (-94)</td>
<td>13.9</td>
<td>ND</td>
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<tr>
<td></td>
<td>E11018 (-08)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>ND</td>
<td>ND</td>
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<td>E308 (-12)&lt;sup&gt;l&lt;/sup&gt;</td>
<td>3.93</td>
<td>3.59</td>
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<td>E310 (-16)&lt;sup&gt;k&lt;/sup&gt;</td>
<td>25.3</td>
<td>18.8</td>
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<td>E316 (-20)&lt;sup&gt;m&lt;/sup&gt;</td>
<td>5.22</td>
<td>3.32</td>
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<td>E410 (-24)&lt;sup&gt;k&lt;/sup&gt;</td>
<td>ND</td>
<td>ND</td>
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<td></td>
<td>E6010 (-28)</td>
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<td>E6011 (-32)</td>
<td>0.05</td>
<td>0.01</td>
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<td>E6012 (-36)</td>
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<td>ND</td>
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<td>E6013 (-46)</td>
<td>0.04</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>E7018 (-44)</td>
<td>0.06</td>
<td>ND</td>
</tr>
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<td>E7024 (-48)</td>
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<td>ND</td>
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<td>E7028 (-52)</td>
<td>0.13</td>
<td>ND</td>
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<td>E8018 (-56)&lt;sup&gt;p&lt;/sup&gt;</td>
<td>0.17</td>
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<td>E9016 (-60)</td>
<td>ND</td>
<td>ND</td>
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<tr>
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<td>E9018 (-64)&lt;sup&gt;q&lt;/sup&gt;</td>
<td>2.12</td>
<td>ND</td>
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<td></td>
<td>ECoCr (-68)</td>
<td>ND</td>
<td>ND</td>
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<td>ENi-Cl (-72)</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>ENiCrMo (-76)&lt;sup&gt;r&lt;/sup&gt;</td>
<td>4.20</td>
<td>ND</td>
</tr>
<tr>
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<td>ENi-Cu-2 (-80)&lt;sup&gt;s&lt;/sup&gt;</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>GMAW&lt;sup&gt;d,e&lt;/sup&gt; (SCC 3-09-052)</td>
<td>E308 (-12)&lt;sup&gt;l&lt;/sup&gt;</td>
<td>5.24</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>E708 (-54)&lt;sup&gt;k&lt;/sup&gt;</td>
<td>0.01</td>
<td>ND</td>
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<td>ER1260 (-10)</td>
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<td>ND</td>
</tr>
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<td></td>
<td>ER5154 (-26)</td>
<td>0.10</td>
<td>ND</td>
</tr>
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<td>ER316 (-20)&lt;sup&gt;y&lt;/sup&gt;</td>
<td>5.28</td>
<td>0.10</td>
</tr>
<tr>
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<td>ERNiCrMo (-76)&lt;sup&gt;w&lt;/sup&gt;</td>
<td>3.53</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>ERNiCu (-80)&lt;sup&gt;x&lt;/sup&gt;</td>
<td>&lt; 0.01</td>
<td>ND</td>
</tr>
<tr>
<td>Welding Process (With Last 2 Digits Of SCC)</td>
<td>Electrode Type</td>
<td>HAP Emission Factor (10⁻¹ g/kg [10⁻¹ lb/10³ lb] Of Electrode Consumed)</td>
<td>EMISSION FACTOR RATING</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>----------------</td>
<td>-------------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>FCAW&lt;sup&gt;δg&lt;/sup&gt; (SCC 3-09-053)</td>
<td>E110 (-06)&lt;sup&gt;g&lt;/sup&gt;</td>
<td>0.02 ND ND 20.2</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>E11018 (-08)&lt;sup&gt;g&lt;/sup&gt;</td>
<td>9.69 ND ND 7.04</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>E308 (-12)</td>
<td>ND ND ND</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>E316 (-20)&lt;sup&gt;ah&lt;/sup&gt;</td>
<td>9.70 1.40 ND</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>E70T (-54)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.04 ND ND</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>E71T (-55)&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.02 ND &lt; 0.01</td>
<td>B</td>
</tr>
<tr>
<td>SAW&lt;sup&gt;h&lt;/sup&gt; (SCC 3-09-054)</td>
<td>EM12K (-10)</td>
<td>ND ND ND</td>
<td>D</td>
</tr>
</tbody>
</table>

<sup>a</sup> 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. ND = no data.

<sup>b</sup> Mass of pollutant emitted per unit mass of electrode consumed. Cr = chromium. Cr(VI) = chromium +6 valence state. Co = cobalt.

<sup>c</sup> Mn = manganese. Ni = nickel. Pb = lead. All HAP emissions are in the PM-10 size range (particles ≤ 10 μm in aerodynamic diameter).

<sup>d</sup> Current = 102 to 225 A; voltage = 21 to 34 V.

<sup>e</sup> Current = 275 to 460 A; voltage = 19 to 32 V.

<sup>f</sup> Type of shielding gas employed will influence emission factors.

<sup>g</sup> Current = 160 to 275 A; voltage = 22 to 34 V.

<sup>h</sup> Current = 450 to 550 A; voltage = 31 to 32 V.

<sup>i</sup> Includes E11018-M

<sup>j</sup> Includes E308-16 and E308L-15

<sup>k</sup> Includes E310-15

<sup>m</sup> Includes E316-15, E316-16, and E316L-16

<sup>n</sup> Includes E410-16

<sup>p</sup> Includes 8018C3

<sup>q</sup> Includes 9018B3

<sup>r</sup> Includes ENiCrMo-3 and ENiCrMo-4

<sup>s</sup> Includes ENi-Cu-2

<sup>t</sup> Includes E308LSi

<sup>u</sup> Includes E70S-3, E70S-5, and E70S-6

<sup>v</sup> Includes ER316L-Si

<sup>x</sup> Includes ERNiCrMo-3 and ERNiCrMo-4

<sup>y</sup> Includes ERNiCu-7

<sup>z</sup> Includes E110TS-K3

<sup>aa</sup> Includes E11018-M

<sup>bb</sup> Includes E70T-1, E70T-2, E70T-4, E70T-5, E70T-7, and E70T-G

<sup>cc</sup> Includes ER316L-Si

<sup>dd</sup> Includes E71T-1 and E71T-11
References For Section 12.19


12.19-8 EMISSION FACTORS 1/95


