

<h1>PPPL</h1>	PRINCETON PLASMA PHYSICS LABORATORY ES&H DIRECTIVES		
	ES&HD 5008 SECTION 9, CHAPTER 15 WELDING, CUTTING, AND BRAZING		
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## CHAPTER 15 WELDING, CUTTING, AND BRAZING

### 15.1 INTRODUCTION

The convenience of metal arc and gas welding and cutting is mainly due to the portability of the equipment. This convenience leads to the performance of construction or repair jobs in locations that may not be designed for such concentrated heat, or mixtures of toxic or explosive gases. Failure to take proper precautions during welding or cutting operations in such locations can present serious fire, explosion, electric shock, and/or health hazards.

### 15.2 SCOPE

This chapter provides guidelines for health hazards commonly associated with welding, cutting, and brazing. In addition to electric shock, other hazards can occur, such as burns to the eyes and skin caused by sparks, molten metal, and ultraviolet and infrared radiation. Fumes and gases generated by welding may include ozone and oxides of nitrogen, which are poisonous. Lead, zinc, silver, chromium, arsenic, cobalt, cadmium, etc., in alloys produce toxic fumes. Paints, coatings, and flux may produce toxic gases and fumes when heated by the flames of the welding torch. Additionally, cadmium, copper, nickel, and zinc are capable of producing metal fume fever. Local exhaust ventilation is required to remove excessive concentrations of air contaminants. Welding in closed, unventilated spaces can result in respiratory irritation or poisoning (see Section 8, Chapter 4).

### 15.3 DEFINITIONS

**Qualified welder** - Persons trained and qualified in accordance with Engineering and Technical Infrastructure Department Procedure EM-002, most recent revision, and any successor documents.

**Site evaluation** - Evaluation of physical and chemical hazards at the work-site performed by PPPL Industrial Hygiene (IH).

**Approved work location** - Welding, cutting, and brazing locations that have been specially configured or designated for that purpose. Field work may be done in locations that have been freed of fire hazards by removal or protection of combustible materials, and by the removal of flammable or explosive materials, liquids, or vapors.

**Adequate** - The terms as used in this chapter refer to compliance with applicable regulations. IH will be the final arbiter of adequacy.

**Suitability** - The terms as used in this chapter, refer to compliance with applicable regulations. IH will be the final arbiter of suitability.

**Protected** - As used in this chapter refers to placed out of harms way or shielded to prevent damage.

**Welder** - As used in this chapter designates any operator of electric or oxygen-fuel gas welding or cutting equipment, or allied processes.

## 15.4 RESPONSIBILITIES

- 15.4.1 Department or Division Heads are responsible for ensuring implementation of this chapter.
- 15.4.2 Line supervisors are responsible for direct implementation of this chapter. Line supervisors shall check with the Mechanical Engineering Division (MED) to ensure that welder's certifications are valid. Line supervisors are also responsible for ensuring that procedures and policies are followed.
- 15.4.3 Industrial Hygiene (IH) is responsible for assisting in the interpretation and implementation of this chapter. Specifically, IH will provide safety, industrial hygiene, and consultative services on an "as needed" basis.
- 15.4.4 Mechanical Engineering Division is responsible for ensuring that qualified welders perform assigned work in accordance with Laboratory policies and procedures.
- 15.4.5 Welders are responsible for:
- understanding the hazards of the operation to be performed, and the procedures to be used to control hazardous conditions,
  - obtaining a Hot Flame Permit from ESU prior to commencement of any operation involving sparks or flame,
  - handling the equipment safely and use it so as not to endanger lives or property,
  - obtaining permission from line supervisors before starting to weld or cut,
  - welding or cutting only so long as conditions are unchanged from those under which permission to weld was granted,
  - welding only where all safety precautions have been met, and
  - posting areas, where necessary, to prevent others from being injured by the welding process.

## 15.5 REQUIREMENTS

- 15.5.1 ANSI Z49.1-1999, "Safety in Welding, Cutting and Allied Processes"
- 15.5.2 29 CFR 1910.251-255, OSHA General Industry Standards for Welding, Cutting, and Brazing
- 15.5.3 NFPA-51, "Standard for the Design and Installation of Oxygen Fuel Gas Systems for Welding Cutting, and Allied Processes."
- 15.5.4 NFPA-51B, "Standard for Fire Prevention during Welding, Cutting, and Other Hot Work."

## 15.6 PRACTICES /PROCEDURES

### 15.6.1 Hot Work Supervision

The control of hot work operations is essential for the prevention of fires, explosions, damage to nearby equipment, and personnel injury. Welding, cutting, or burning shall not be permitted without obtaining a "hot flame" permit from the Emergency Services Unit (ESU). In all cases where permission has been granted to weld, cut or burn, the supervisor of the operator performing the work shall be aware of the details of the job. Depending on the inherent danger of the work, the supervisor shall be satisfied that all safety and health conditions have been met and are followed during the operation.

### 15.6.2 Cylinders - Handling and Use

- A. Portable cylinders used for the storage and transporting of compressed gases shall be constructed, maintained, and used in accordance with the ES&H Manual, Section 9, Chapter 2, "Compressed Gas Cylinder Safety."
- B. Cylinders containing oxygen, acetylene or other fuel gas shall not be taken into confined spaces.

### 15.6.3 General Area Protection

- A. The precautions outlined in the ES&H Manual, Section 5, Chapter 3, Paragraph 3.13.3, shall be taken to prevent fires due to the exposure of combustibles to the effects of welding, cutting, or brazing operations. It shall be the responsibility of the welding operator to look on the "other side" of the wall, floor, or other structure to assure that welding or cutting operations will not damage materials or equipment in adjacent areas.
- B. Welding, cutting, and brazing operations shall be conducted on a routine basis only in approved work locations. Fieldwork may be done in other locations that have been freed of fire hazards by removal or protection of combustible materials, or by the removal of flammable and explosive materials, liquids, or vapors. Suitable precautions shall be taken against the re-accumulation of such materials.
- C. Welding or cutting torch operations are not permitted in or on the outer surface of flammable storage rooms, tanks, or other containers which contain or have contained flammable or explosive materials, liquids, or vapors unless and until applicable precautionary procedures have been completed and verified by an industrial hygienist.
- D. Field welding, brazing, or cutting operations are not to be performed on a steel wall or floor until a fire watch is posted on both sides. Fire watches are also required for all "hot work" being conducted in normal repair areas such as machine shops. Fire watch personnel shall remain at their station at least 30 minutes after the job is completed to ensure that no smoldering fires have been started. Personnel protective equipment shall be provided to all fire watches by cognizant supervisors.
- E. Fire extinguishing equipment having a minimum rating of 2-A: 20-B: C shall be maintained near all welding and cutting operations. In the event an electrical fire is started, electricity to the affected equipment or area should be turned off to remove the ignition source before attempting to extinguish the fire.
- F. Workers or other persons adjacent to the welding areas shall be protected from the radiant energy and spatter of welding and cutting by non-combustible or flame-resistant screens, or shall be required to wear eye and face protection, and protective clothing.

- G. Where arc welding is regularly carried out, adjacent walls and other surfaces shall have low reflectivity to ultraviolet radiation.

#### 15.6.4. Eye and Face Protection

- A. Eye and face protection shall comply with ANSI Z87.1 and Section 8, Chapter 6 of the ES&H Manual.
- B. Specifications for eye protection are provided in the following table:

**Table 15.1**

<b>Operation</b>	<b>Electrode Size 1/32 in. (mm)</b>	<b>Arc Current (A)</b>	<b>Minimum Protective Shade</b>	<b>Suggested Shade (Comfort)</b>
Shielded metal arc Welding	Less than 3 (2.5)	Less than 60	7	–
	3 - 5 (2.5 - 4)	60 - 160	8	10
	5 - 8 (4 - 6.4)	160 - 250	10	12
	More than 8 (6.4)	250 - 550	11	14
Gas metal arc welding and flux cored arc welding		Less than 60	7	–
		60 - 160	10	11
		160 - 250	10	12
		250 - 500	10	14
Gas tungsten arc welding		Less than 50	8	10
		50 - 150	8	12
		150 - 500	10	14
Arc carbon	(Light)	Less than 500	10	12
Arc cutting	(Heavy)	500 - 1000	11	14
Plasma arc welding		Less than 20	6	6 to 8
		20 - 100	8	10
		100 - 400	10	12
		400 - 800	11	14
Plasma arc cutting	(Light)	Less than 300	8	9
	(Medium)	300 - 400	9	12
	(Heavy)	400 - 800	10	14
Torch Brazing		–	–	3 or 4
Torch Soldering		–	–	2
Carbon arc welding		–	–	14

	Plate Thickness		Suggested Shade (Comfort)
	in.	mm	
Gas welding			
Light	Under 1/8	Under 3.2	4 or 5
Medium	1/8 to 1/2	3.2 to 12.7	5 or 6
Heavy	Over 1/2	Over 12.7	6 or 8
Oxygen cutting			
Light	Under 1	Under 25	2 or 4
Medium	1 to 6	25 to 150	4 or 5
Heavy	Over 6	Over 150	5 or 6

Note: In gas welding or oxygen cutting where the torch produces a high intensity yellow light, it is desirable to use a filter or lens that absorbs yellow at or near the D line of sodium in the visible spectrum (approximately 450 nm).

- C. Personnel assigned Fire Watch duty are required to wear appropriate goggles or safety glasses as protection from injurious ultraviolet radiation from adjacent arc welding, as well as from flying objects. Typically, a lighter filter shade may be used if no direct viewing of the arc occurs.

#### 15.6.5 Respiratory Protection

- A. Adequate ventilation must be provided in confined spaces during welding, brazing, burning, and cutting operations using either installed ventilation systems or auxiliary ventilation systems. The ES&H Manual, Section 8, Chapter 4, applies.
- B. Where adequate ventilation is not provided, operators and helpers shall wear appropriate metal fume respirators during welding, cutting, or brazing operations that involve filler materials or base metals capable of emitting toxic fumes.
- C. Specific respiratory protection requirements are provided in the ES&H Manual, Section 8, Chapter 7.

#### 15.6.6 Protective Clothing:

- A. The nature, size, and location of the work shall determine appropriate protective clothing required for any welding operation. It is the responsibility of the cognizant supervisor to provide and ensure use of appropriate personal protective equipment. Should any questions arise as to appropriateness of equipment, the Industrial Hygienist should be consulted.
- B. Protective means which may be employed include:
  1. Welders should wear flameproof gauntlet gloves except when engaged in light GTAW work. Gloves shall be worn when removing or replacing electrodes, or handling

energized holders, tables, or equipment. The gloves shall be dry and in good condition.

2. It is recommended that a welder's jacket or sleeves and apron be worn while arc welding. Helmets and face shields shall be fitted with the proper filter and cover lenses. Flameproof aprons, jackets, and leggings made of suitable material should be worn as protection against radiated heat and sparks.
3. Clothing shall be selected to minimize the potential for ignition, burning, trapping hot sparks, or electric shock. Heavier materials such as woolen clothing are preferable to lighter materials because they are more difficult to ignite. Cotton clothing must be chemically treated to reduce its combustibility. Treated clothing must be handled in accordance with manufacturers' specifications to avoid reduction of flame resistance during laundering. Clothing made of 100 percent synthetic fabric cannot be worn because of the danger of it adhering to the skin, if burned or melted. All outer clothing shall be free from oil or grease.
4. Sparks may lodge in rolled-up sleeves or pockets of clothing or cuffs of overalls or trousers. Therefore, it is recommended that sleeves and collars be kept buttoned and pockets and cuffs be eliminated. Lighters and matches should not be carried by the operator.
5. Operators shall wear approved protective clothing. Low cut shoes with unprotected tops should not be used. Molder shoes/boots (covered lace or smooth toe, high-topped, elastic gore), or similar boots are recommended.
6. Other protective clothing should be worn as needed, such as: flame-resistant aprons, leggings, sleeves, hearing protection, and caps.

#### 15.6.7 Ventilation

##### A. General

1. Local exhaust ventilation is the most effective means of controlling airborne contaminants produced by welding or cutting operations that produce toxic fumes. Welding shops should be equipped with an exhaust ventilation system capable of removing the contaminants from the air near the source of generation (the welding arc) and exhausting the air through an air cleaning device or directly outside. Fire-proof flexible duct and hoods, as an example, are constructed so as to be moved near the welding site on the workbench. The air-handling system should move at least 100 cubic feet of air per minute across the welding site.
2. When the work site is located, the movable hood shall be placed 6 to 10 inches from the welding arc.
3. All permanent brazing operations where toxic materials are used shall be located on a down-draft bench or table. Air is drawn downward into the duct work and vented as described in A, above. Other control measures may be utilized if approved by IH.
4. Toxic welding and brazing fumes are not to be vented into occupied areas of buildings.

##### B. Work in Restricted Access and Confined Spaces

1. Before entering or working in restricted access spaces, the following provisions shall be strictly observed. The ES&H Manual, Section 8, Chapter 5, describes the Laboratory's Confined Space Policy. This chapter (Section 9, Chapter 15)

supplements Section 8, Chapter 5. For the purpose of this chapter, a restricted access space shall mean:

- a. A space with only one exit.
  - b. A space where equipment or structural barriers prevent easy exit or entrance.
2. Ventilation must be available to permit work in restricted access spaces. When sufficient ventilation cannot be obtained without blocking the means of access, personnel in the confined space shall be protected by air-line respirators or self-contained breathing apparatus.
  3. When welding or cutting is being performed in any restricted access space, the gas cylinders and heavy welding or cutting equipment shall be left on the outside. Before operations are started, heavy portable equipment mounted on wheels shall be securely blocked to prevent accidental movement.
  4. A Safety Watch shall be stationed outside, shall observe the welding operator at all times, and in case of emergency, shall immediately shut off the gas or welding machine and render such other help as the occasion warrants.
  5. When a welder must enter a restricted access space through a manhole or other small opening, safety belts, harnesses, and lifelines shall be used for quick removal of welder in case of emergency. The safety apparatus will be attached to the welder in a way to avoid becoming stuck in a small exit opening.
  6. When the access fitting to a restricted access space is remotely controlled, positive measures shall be taken to secure remote control equipment to avoid accidental closing of doors while welding or cutting operations are in progress. This shall include, but not be limited to, compliance with the Lockout/Tagout System as presented in the PPPL Procedures Manual (ESH-016).
  7. When work in a restricted access space is to be suspended for 1 hour or more, electrodes shall be removed from the holders of arc-welding equipment and one of the two following precautions shall be taken:
    - a. All arc-welding equipment shall be removed from the restricted access space.
    - b. Equipment shall be disconnected from the source of power. This shall always be performed if the equipment is to be left overnight.
  8. To eliminate the possibility of gas escaping through leaks or improperly closed valves in gas tungsten arc welding (GTAW), gas metal arc welding (GMAW) or gas welding equipment, the torch valves shall be closed and the gas supply to the welding head or torch positively shut off between the gas supply and outside boundary of the restricted access space. The foregoing does not apply to shop spaces in which active storage of welding equipment has been authorized. Inert-gas welding equipment and gas torches shall remain in restricted access spaces only for the period necessary to perform the actual torch operation.
- C. All provisions of the ES&H Manual, Section 8, Chapter 5, "Confined Spaces," apply to entry and work within voids, closed, confined, restricted access, and other poorly ventilated spaces.

### 15.6.8 General Safety Precautions

- A. Precautions - Operators of arc welding and cutting equipment shall adhere to the following precautions:
1. Before starting operations, make certain that the welding machine frame is grounded, that neither terminal of the welding generator is bonded nor grounded to the frame of the welder, and that all electrical connections are attached firmly to the work, not merely laid loosely upon it. Use only electrode holders and cable that are designed for arc welding, with adequate capacity to handle the maximum rated current required.
  2. Stand on dry surface or insulating material if surface is NOT completely dry.
  3. Do not work alone. An individual shall be nearby to act as fire watch, as well as to initiate rescue, if needed. Immediate medical attention of electrical shock may help prevent serious consequences.
  4. Never permit the metal part of the electrode or the electrode holder to touch the bare skin or any damp clothing. Do not loop the welding cable over the shoulder or other body parts. Operators can be dragged off staging or scaffolds when the cables are fouled by other workers, moving equipment, etc.
  5. Do not hold an energized electrode holder under the arm at any time. If an insulated surface or insulated holding peg is not available, remove the electrode and lay the insulated holder on the floor or other adjacent nonmetallic surface.
  6. When stopping work shut off all gas supply lines, remove electrode from electrode holder, de-energize the equipment and/or disconnect welding supply cable from the welding machine.
  7. Workers or other persons adjacent to areas in which welding is performed shall be adequately protected from the visible and ultraviolet non-ionizing radiation of the arc by screens, goggles, or other suitable means in order to prevent ultraviolet radiation burns in the eyes.
  8. When welding in a space, which is entirely screened on all sides, arrange the screens to clear the floor so as not to restrict ventilation from carrying off the fumes and smoke from the operation.
  9. Where conditions are crowded and welding is close to other personnel, the welder shall take special care to ensure that the electrode and holder do not touch nearby occupants while welding is in progress.
  10. When using portable machines, ensure that the primary supply cables are separately located and do not become entangled with welding supply cables.
  11. Work and electrode lead cables shall be frequently inspected for wear and damage. Cables with damaged insulation or exposed bare conductors shall be replaced. Joining lengths of work and electrode cables shall be done by the use of connecting materials specifically intended for the purpose. The connecting materials shall have insulation adequate for the service conditions.
  12. Keep welding cables dry, where practical, and free from grease and oil to prevent premature breakdown of the insulation, which could cause short circuits.

13. When it is necessary to carry cables some distance from the machine, cables should be suitably supported overhead. If this cannot be done and cables are laid on the floor, they should be protected in such a manner that cables will not be damaged or interfere with safe passage of personnel. Special care should be taken to ensure that welding supply cables are not in contact with power supply cables, lighting circuits, or to any equipment that has magnetic tapes or depends upon a magnetic principle for operation. Welding cables shall be protected when transported through openings and doors.
  14. Welding equipment used in the open shall be protected from inclement weather conditions to prevent short circuiting.
  15. Foot pedal controls for metal inert gas (MIG) and tungsten inert gas (TIG) welding apparatus shall be adequately protected and under the positive control of the operator while equipment is energized. This includes both power switches and wire feed apparatus.
- B. Protection from Shock
1. All electric power circuits, whether AC or DC, high or low voltage, are a potential source of danger. Avoidance of electric shock is largely within the control of the welding operator.
  2. Handle any electric circuit with extreme caution. The reference to "any electric circuit" is particularly emphasized because the welding operator not only handles the welding circuit, but also may handle portable lights, portable motor-driven tools, and in many instances may handle switches or portable cables with one side of the arc welder connected to the power supply.
- C. Gas Metal Arc Welding: Due to the greater intensity of radiant energy during inert-gas metal arc welding, the skin shall be covered completely to prevent burns or other damage by ultraviolet light. Shirts shall be dark in color to reduce reflection to the face underneath the helmet. Exposed cotton clothing shall not be worn. Never use nitrogen as a torch shielding gas. In its elemental state, nitrogen makes up approximately 78 percent of the atmosphere and is relatively harmless. However, when heated in the presence of oxygen, toxic oxides of nitrogen are quickly formed. Effects of these gases range from anesthetic qualities to toxic (acid) gases, which can destroy lung tissue on contact.
- D. Radiological Health Hazards: Special problems will be encountered during welding, brazing, or cutting of activated (radioactive) metals such as those found in the Tokamak Fusion Test Reactor (TFTR) and its ancillary equipment. Specific procedures for this type of work will be issued by the ES&H Health Physics Group under a separate cover and are beyond the scope of this document.
- E. Arc-Air Gouging or Cutting - The operation of the arc-air gouging or cutting equipment shall be performed only by trained, qualified personnel. The operator must always wear gloves and an arc welding type helmet. Protection from flying slag must be provided for personnel and surrounding structures.

### 15.6.9 Health Hazards

#### A. General

In addition to the personnel hazards from burns, electricity, radiation, fire, explosion, asphyxiation, and suffocation, under certain conditions there may be health hazards due to gases, fumes, or dusts caused by the welding operations. These hazards make it necessary that welding be done either in properly ventilated spaces with the use of effective local exhaust ventilation, or with the use of approved respirators, or both. Actual hazards are almost entirely due to the presence of gases, dusts, and fumes such as those containing lead, zinc, cadmium, fluorine, or compounds thereof and oxides of nitrogen or extreme heat. Consideration must also be given to the hazards of accumulation of purge gases in compartments. A variety of poisonous chemicals, when inhaled in heavy doses during welding, cutting, and brazing, can cause temporary or long-lasting harm to health. Industrial Hygiene (IH) should be notified if any of these hazards are known or suspected to exist. Upon confirmation by IH, appropriate protective measures outlined in this chapter shall be implemented. These include, but are not limited to:

1. Lead - Lead fumes are one of the more common dangers encountered by welders and cutters. When welding around and through lead-based paints, considerable lead oxide fumes are evolved. Symptoms include stomach and muscle cramps, nausea, loss of appetite, and insomnia.
2. Acetylene - Acetylene will displace oxygen in a closed compartment, thus reducing breathable oxygen to a level that will asphyxiate. The major hazard of acetylene is the explosive potential. Because acetylene becomes unstable at excessive pressures, do not pressurize it above 15 psi gauge.
3. Antimony - Antimony is alloyed with many metals. Antimony fumes irritate the skin, eyes, and mucous membranes. Symptoms of excessive exposure to airborne antimony are metallic taste, vomiting, and stomach distress.
4. Arsenic - Arsenic may be encountered in welding and cutting operations as a component of various alloys. Welding or cutting on metals painted with arsenic compounds is hazardous. Common symptoms of excessive exposure are skin irritation, irritation of nasal passages, mild irritation of the lungs and eyes, and laryngitis.
5. Cadmium - Cadmium is used frequently in steel and is an alloying element in some metals. Exposure to high concentrations of cadmium fumes can result in severe lung irritation, cough, and shortness of breath.
6. Carbon Monoxide - Welding and cutting can produce hazardous atmospheric levels of carbon monoxide. In addition, welding operations that use carbon dioxide as the inert gas shield produce hazardous concentrations of carbon monoxide in unventilated spaces. Common symptoms of overexposure include dull headache, nausea, dizziness, and ringing in the ears.
7. Chromium - Chromium is the primary alloying element in stainless steel. Welding of stainless steel should not be conducted in confined, unventilated spaces. Local exhaust ventilation of welding fumes is required. Chromium is extremely poisonous and irritating to the skin, eyes, and nasal passages.
8. Cobalt - Cobalt is an alloying element in high-strength, high-temperature metals. Inhalation of cobalt fumes results in shortness of breath and coughing.

9. Chlorinated Hydrocarbons (Degreasing Solvents) - The vapors of these solvents, such as those containing trichloroethylene and perchloroethylene, are decomposed by heat and ultraviolet radiation forming poisonous and irritating gases including phosgene and chlorine gas. Although mildly irritating to mucous membranes, phosgene causes pulmonary edema. This condition, in which the lungs fill with fluid, can be fatal within a short time. Operations involving these solvents must be located so that the vapors from these operations will not reach or be drawn into the atmosphere surrounding molten weld metal or the arc.
10. Fluorides - Fluoride compounds are used as coatings in various welding rods. Excessive exposure will irritate the eyes, nose, and throat. Repeated exposure to high concentrations can result in pulmonary edema and death.
11. Manganese - Manganese is a constituent of many arc welding electrodes. Heavy exposure to manganese fumes may result in weakness and difficulty in balance and speech.
12. Nitrogen Oxides - The intense energy produced by an arc can produce poisonous quantities of nitrogen oxides in closed spaces. This dangerous gas, although mildly irritating to the eyes and nose, can cause pulmonary edema (a condition in which the lungs fill with fluid, often with a fatal outcome).
13. Ozone - Ozone is created by the ultraviolet light of the arc. It is intensely irritating to the eyes, nose, and throat. Ozone can cause headache and chest pain.
14. Zinc or Copper - Fumes containing zinc or copper compounds may produce symptoms of nausea, dizziness, or fever, sometimes called "metal fume fever."

## 15.7 REFERENCES

American Welding Society / American National Standards Institute, Z49.1: 1999, "Safety In Welding, Cutting, and Allied Processes"

Occupational Safety and Health Administration, 29 CFR 1910.251-255

American Industrial Hygiene Association, Welding Health and Safety

Engineering, Technology and Infrastructure Department: Fabrication, Operations & Maintenance Division Procedure EM-002, General Welding and Torch Brazing Procedure