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This document is an abridged edition of Criteria for a Recommended Standard: Welding, Brazing, and Thermal Cutting, DHHS (NIOSH) Publication No. 88-110, NTIS No. PB-88-231-774. The full text of the document, including a list of the references cited, is available from the following:

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FOREWORD

The purpose of the Occupational Safety and Health Act of 1970 (Public Law 91-596) is to ensure safe and healthful working conditions for every working person and to preserve our human resources by providing medical and other criteria that will ensure, insofar as practicable, that no worker will suffer diminished health, functional capacity, or life expectancy as a result of his or her work experience. The Act authorizes the National Institute for Occupational Safety and Health (NIOSH) to develop and recommend occupational safety and health standards and to develop criteria for improving them. By this means, NIOSH communicates these criteria both to regulatory agencies and others in the community of occupational safety and health.

Criteria documents provide the basis for the occupational health and safety standards sought by Congress. These documents generally contain a critical review of the scientific and technical information available on the prevalence of hazards, the existence of safety and health risks, and the adequacy of control methods. NIOSH distributes these documents to health professionals in academia, industry, organized labor, public interest groups, and other appropriate government agencies.

This criteria document on welding, brazing, and thermal cutting reviews available information on the health risks for workers in these occupations and provides criteria for eliminating or minimizing the occupational risks these workers may encounter. Evidence from epidemiologic studies and case reports of workers exposed to welding emissions clearly establishes the risk of acute and chronic respiratory disease. The major concern, however, is the excessive incidence of lung cancer among welders. A large body of evidence from regional occupational mortality data, case control studies, and cohort studies indicates that welders generally have a 40% increase in relative risk of developing lung cancer as a result of their work experiences. The basis of this excess risk is difficult to determine given uncertainties about smoking habits, possible interactions among the various components of welding emissions, and possible exposures to other occupational carcinogens, including asbestos. The severity and prevalence of other respiratory conditions such as chronic bronchitis, pneumonia, and decrements in pulmonary function are not well characterized among welders, but these effects have been observed in both smoking and nonsmoking workers in this occupation. Excesses in morbidity and mortality among welders appear to exist even when exposures have been reported to be below current Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) for the many individual components of welding emissions.

An exposure limit for total welding emissions cannot be established because the composition of welding fumes and gases varies for different welding processes and because the various components of the emissions may interact to produce adverse health effects. NIOSH therefore recommends that exposures to all welding emissions be reduced to the lowest feasible concentrations using state-of-the-art engineering controls and work practices. Exposure limits for individual chemical or physical agents are to be considered upper boundaries of exposure. Presently it is not possible to associate a particular health hazard with a specific component of total welding emissions; however, the risk of lung cancer for workers who weld on stainless steel appears to be associated with exposure to fumes that contain nickel and chromium. NIOSH has previously recommended to OSHA that exposures to specific forms of these metals be treated as exposures to occupational carcinogens. Future research may make it possible to differentiate risks associated with a particular exposure. NIOSH will evaluate such data as they become available and revise this recommended standard as appropriate.

The Institute takes sole responsibility for the conclusions and recommendations presented in this document. All reviewers' comments are being sent with this document to the Occupational Safety and Health Administration (OSHA) for consideration in standard setting.

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ABSTRACT

~~This~~ The document examines the occupational health risks associated with welding, brazing, and thermal cutting, and it provides criteria for eliminating or minimizing the risks encountered by workers in these occupations. The main health concerns are increased risks of lung cancer and acute or chronic respiratory disease.

The data in this document indicate that welders have a 40% increase in relative risk of developing lung cancer as a result of their work experience. The basis for this excess risk is difficult to determine because of uncertainties about smoking habits, possible interactions among the various components of welding emissions, and possible exposures to other occupational carcinogens. However, the risk of lung cancer for workers who weld on stainless steel appears to be associated with exposure to fumes that contain nickel and chromium.

The severity and prevalence of noncarcinogenic respiratory conditions are not well characterized among welders, but they have been observed in both smoking and nonsmoking workers in occupations associated with welding. Excesses in morbidity and mortality among welders exist even when reported exposures are below current Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) for the many individual components of welding emissions.

An exposure limit for total welding emissions cannot be established because the composition of welding fumes and gases varies for different welding processes and because the various components of a welding emission may interact to produce adverse health effects. NIOSH therefore recommends that exposures to all welding emissions be reduced to the lowest feasible concentrations using state-of-the-art engineering controls and work practices. Exposure limits for individual chemical or physical agents are to be considered upper boundaries of exposure.

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ABBREVIATIONS

ACGIH --American Conference of Governmental Industrial Hygienists
Ag --silver
ANSI --American National Standards Institute
AWS --American Welding Society
BUN --blood urea nitrogen
CBC --complete blood count
cfm --cubic feet per minute
CFR --Code of Federal Regulations
cm --centimeter
Co --cobalt
Cr(VI) --chromium(VI)
Cu --copper
dB --decibel
dBA --decibels measured on the A scale
F --fluorine
FEV_1 --forced expiratory volume in one second
fpm --feet per minute
ft --foot
FVC --forced vital capacity
hr --hour
IDLH --immediately dangerous to life or health
ILO --International Labour Office
in. --inch
J --joule
kW --kilowatt
m --meter
mg --milligram
min --minute
mm --millimeter
mppcf --millions of particles per cubic foot
MSHA --Mine Safety and Health Administration
MW --molecular weight
mWsec --milliwatt second
Ni --nickel
NIOSH --National Institute for Occupational Safety and Health
nm --nanometer
NO_2 --nitrogen dioxide
OSHA --Occupational Safety and Health Administration
Pb --lead
PEL --permissible exposure limit

PFT	--pulmonary function test
ppm	--part per million
REL	--recommended exposure limit
sec	--second
SHE(O)	--sentinel health event (occupational)
Sn	--tin
SnH_4	--tin hydride
STEL	--short-term exposure limit
SPF	--sun protection factor
TLV®	--threshold limit value
TWA	--time-weighted average
μg	--microgram
UV	--ultraviolet
V	--vanadium
ZPP	--zinc protoporphyrin

I. RECOMMENDATIONS FOR A STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that worker exposure to hazards associated with welding processes in the workplace be controlled by complying with the provisions presented in Chapter I of this document. Chapters II and III provide additional detail concerning the implementation of these provisions. Adherence to these recommendations should prevent or greatly reduce the risk of adverse health effects among exposed workers. These recommendations are designed to protect the health and provide for the safety of workers engaged in welding over a working lifetime; they are to be used as an adjunct to existing NIOSH recommendations. The following sections shall replace or modify the provisions for welding, cutting, and brazing contained in 29 CFR* 1910.251-254, 1915.51-57, and 1926.350-354. Other specific requirements contained in those regulations and not addressed in the NIOSH recommended standard shall be retained.

Section 1 - Definitions

(a) **Worker** is any person who is or may reasonably be expected to be exposed to chemical and physical hazards associated with welding processes.

(b) **Exposure Limit** is the concentration of a chemical or physical agent emitted during welding that shall not be exceeded in the workplace. The NIOSH recommended exposure limit (REL) shall be used when available for any chemical or physical agent. In the absence of a NIOSH REL, the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) shall be used unless a more restrictive limit has been recommended by a recognized voluntary consensus group or committee. When neither a NIOSH REL nor an OSHA PEL exists, an appropriate consensus-group- or committee-recommended exposure limit shall be used. Although NIOSH has not evaluated the adequacy of such exposure limits, their adoption would be a prudent public health measure and would afford a greater degree of protection than using no limit.

The OSHA PELs shall not be exceeded under any circumstances. The Appendix lists some of the more common chemical and physical agents that may be found in the workplace or near workers engaged in welding.

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* Code of Federal Regulations. See CFR in References, which may be found in the full-length criteria document (Criteria for a Recommended Standard: Welding, Brazing, and Thermal Cutting).

(c) **Welding** includes those processes that join or cut pieces of metal by heat, pressure, or both. These processes differ in the way heat is created and applied to the parts being joined; they comprise a group of processes referred to as welding, brazing, and thermal cutting.

Section 2 - Recommended Exposure Limits

Exposures to chemical and physical agents shall be controlled so that workers are not exposed to concentrations above the exposure limits (see Definitions, Section 1(b))

An exposure limit for total welding emissions cannot be established because the composition of welding emissions (chemical and physical agents) varies for different welding processes and because the various components of a welding emission may interact to produce adverse health effects. Thus even compliance with specific chemical or physical agent exposure limits may not ensure complete protection against an adverse health effect. Therefore, as a prudent public health measure, the employer shall reduce worker exposures to all chemical and physical agents associated with welding to the lowest concentrations technically feasible using current state-of-the-art engineering and good work practice controls. Exposure limits for individual chemical or physical agents are to be considered upper boundaries of exposure.

Section 3 - Medical Monitoring

The following requirements supplement existing medical monitoring measures that NIOSH recommends for workers exposed to specific chemical or physical agents. The objective of these requirements is to provide an additional level of monitoring for workers who may be exposed to welding emissions or who may have been adversely affected by them in the past. NIOSH recommended standards and existing OSHA standards shall be used to determine the need for specific medical tests. (See Appendix B of the full-length criteria document for published sources of NIOSH recommended standards for some specific chemical and physical agents.)

(a) General

(1) The employer shall institute a medical monitoring program for all workers who are or may reasonably be expected to be exposed to hazards from welding processes.

(2) The employer shall ensure that all medical examinations and procedures are performed by or under the direction of a licensed physician.

(3) The employer shall provide the required medical monitoring without loss of pay or other cost to the workers, and at a reasonable time and place.

(b) Preplacement Medical Examination

The preplacement medical examination shall include the following items at a minimum:

(1) A comprehensive work and medical history that emphasizes identification of existing medical conditions and previous occupational exposure to chemical or physical health hazards, particularly those associated with welding processes.

(2) A comprehensive physical examination.

(3) A thorough examination of the respiratory system, including baseline pulmonary function tests (at a minimum, forced vital capacity [FVC] and forced expiratory volume in one second [FEV_1]) using the current recommendations of the American Thoracic Society regarding testing procedures and equipment. (Guidelines are given in Appendix C of the full-length criteria document.)

(4) A posterio-anterior chest radiograph that is interpreted by qualified B readers (i.e., those who have passed the NIOSH proficiency examination) using the current recommendations of the International Labour Office (ILO) regarding the classification of pneumoconiosis.

(5) An examination of the skin and eyes for scars that appear to have been caused by burns. The locations of such scars should be noted.

(6) A baseline cardiovascular evaluation.

(7) A baseline audiogram.

(8) A thorough ophthalmologic evaluation.

(c) Periodic Medical Examination

A periodic medical examination shall be provided at least annually to all workers. The following conditions may shorten the interval between examinations and the need for special medical tests:

(1) Workers reporting signs or symptoms associated with exposure to welding emissions, and

(2) Airborne concentrations of specific agents that exceed exposure limits.

Periodic medical examinations shall include the following:

(1) Updates of medical and occupational histories. These shall include a description of the following items based on an interview of the worker and records maintained by the employer: the type of welding performed, metals worked and fluxes used, locations and

conditions (e.g., confined spaces and hot environments), and potentially hazardous exposures not directly related to welding (e.g., chlorinated hydrocarbons).

(2) An evaluation of the respiratory system. Because of the potential for chronic respiratory disease, this evaluation shall include spirometry at intervals indicated by the judgment of the examining physician. Workers with symptomatic, spirometric, or radiographic evidence of pulmonary impairment or disease shall be counseled about the risks of further exposure. Smokers shall be counseled about how smoking may enhance the adverse effects of other respiratory hazards.

(3) Posterio-anterior chest radiographs interpreted by qualified B readers (i.e., those who have passed the NIOSH proficiency examination) using the current recommendations of the International Labour Office (ILO) regarding the classification of pneumoconiosis. These radiographs shall be performed at intervals determined by the examining physician. Periodic chest radiographs are recommended for monitoring workers exposed to fibrogenic respiratory hazards (e.g., quartz). At a minimum, chest radiographs should be obtained at 1- to 5-year intervals, depending on the nature and intensity of exposures and the related health risks. A recent chest radiograph obtained for other purposes (e.g., upon hospitalization) may be substituted for the periodic chest radiograph if it is made available and is of acceptable quality.

(4) An examination of the skin and eyes for scars that appear to have been caused by burns. The locations of such scars should be noted.

(5) An evaluation of the cardiovascular system.

(6) An ophthalmological evaluation.

(7) An audiogram.

(8) Other tests deemed appropriate by the attending physician.

Section 4 - <u>Labeling and Posting</u>

Workers shall be informed of exposure hazards, of potential adverse health effects, and of methods to protect themselves in accordance with 29 CFR 1910.1200, Hazard Communication. Manufacturers of welding materials shall warn employers and workers of the potentially hazardous components of the filler metals, electrodes, and flux materials by applying precautionary labels to the packing containers. Such labels shall indicate the identity of the hazardous agents and the adverse health effects that may result from exposure. In addition, the employer must comply with the labeling and posting requirements contained in the following subsections.

(a) Labeling

All labels and warning signs shall be printed in both English and in the predominant language of non-English-reading workers. Workers who cannot read the language used on labels and posted signs shall be identified so that they may receive information regarding hazardous areas and be informed of the instructions printed on labels and signs.

(1) Containers of filler metal, electrodes, and flux materials shall bear warning labels containing the following information at a minimum:

- The following warning:

  WARNING
  Welding produces hazardous fumes and gases.
  Avoid breathing them.
  Use adequate ventilation

- Instructions for emergency first aid
- Instructions for safe use
- Instructions for the type of personal protective clothing or equipment to be worn

(2) Labels shall identify the hazardous constituents of the container's contents.

(3) The following information shall be included on the labels of containers holding filler metal, electrodes, and flux materials that contain agents identified as carcinogens by NIOSH and OSHA:

- The name of the potential occupational carcinogen and a description of its health hazards. For materials containing carcinogens, the warning label listed in Section 3(a)(1) above shall include the following statement:

  Fumes or gases from this [filler metal, electrode, or flux material] may cause cancer.

- Instructions for avoiding inhalation of fumes and excessive skin or eye contact with them.

(4) Base metals that contain or are coated with materials containing carcinogens or other toxic metals (e.g., lead or mercury) shall be clearly labeled or marked to indicate their contents before being welded.

(b) Posting

(1) In areas where welding is conducted, the following sign shall be posted in readily visible locations:

WARNING
Welding produces hazardous fumes, gases, and radiation.
Appropriate personal protective equipment is required.
DO NOT LOOK AT ARC. EYE INJURY MAY OCCUR.

(2) Signs posted in work areas where emissions contain carcinogens shall differ from the preceding example, as follows:

- The word "DANGER" shall be used instead of "WARNING."

- The name of the carcinogen shall be included along with a warning describing its health hazards. If a carcinogen is contained in the base or filler metals, electrodes, or fluxes, the warning shall include the statement, "Fumes or gases from [the base metal(s), filler metal, electrode, or flux] may cause cancer," with the type(s) of base or filler metals, electrodes, or fluxes specified.

- Any requirements for personal protective clothing and equipment shall also be stated.

Section 5 - Protective Clothing and Equipment

Engineering controls and safe work practices shall be used to keep the emissions from welding processes below the exposure limits specified in Chapter I, Section 2 of this document. In addition, the employer shall provide protective clothing and equipment to workers as follows:

(a) Clothing

(1) The employer shall provide and require the use of appropriate protective clothing as follows:

- Fire-resistant gauntlet gloves and shirts with sleeves of sufficient length and construction to protect the arms from heat, ultraviolet (UV) radiation, and sparks. Wool and leather clothing are preferable because they are more resistant to deterioration and flames than cotton or synthetics.

- Fire-resistant aprons, coveralls, and leggings or high boots.

- Fire-resistant shoulder covers (e.g., capes), head covers (e.g., skullcaps), and ear covers for workers doing overhead work.

(2) The employer shall do the following for workers welding with highly toxic materials (e.g., carcinogens, lead, fluorides):

- Provide and require the use of work uniforms, coveralls, or similar full-body coverings.
- Provide lockers or other closed areas to store work clothing separately from street clothing.
- Collect work clothing at the end of each work shift and provide for laundering. Clothing treated for fire resistance may need to be retreated after laundering. Laundry personnel shall be adequately informed of the potential hazards and protected from any contaminants on the work clothing.

(3) The employer shall ensure that protective clothing is inspected, maintained, and worn to preserve its effectiveness.

- Clothing shall be kept reasonably free of oil or grease.
- Clothing treated for fire resistance shall be retreated after laundering if necessary.
- Upturned sleeves or cuffs shall be prohibited.
- Sleeves and collars shall be kept buttoned.

(b) Eye and Face Protection

(1) The employer shall provide and require the use of the following protective gear for the eyes and face:

- Welding helmets that meet the requirements of 29 CFR 1910.252(e)(2)(ii), Specifications for Protectors.
- Welding helmets with approved UV radiation filter plates, or safety spectacles with side-shields, or goggles for all workers exposed to arc welding or cutting processes.
- Goggles or similar eye protectors with filter lenses for workers exposed to oxyfuel gas welding, brazing, or cutting.
- Goggles or similar eye protectors with transparent lenses shall be used for workers exposed to resistance welding or to mechanical cleaning or chipping operations.

(2) The shade numbers used for filter plates or lenses shall meet the requirements of 29 CFR 1910.252(e)(ii).

(3) Eye and face protectors shall be maintained and periodically cleaned and inspected by the employer. Eye and face protectors shall be sanitized before being used by another worker.

(c) Respiratory Protection

Engineering controls and good work practices shall be used to control respiratory exposure to airborne contaminants. Workers shall use respiratory protection only when controls are not technically feasible, when certain routine or nonroutine short-term operations (e.g., maintenance and repair or emergencies) are performed, or when engineering and work practice controls do not reduce the concentration of the contaminant below the exposure limit.

(1) When respirators are used, a complete respiratory protection program shall be instituted as set forth in 29 CFR 1910.134. This program shall include the following elements at a minimum:

- A written program for respiratory protection (e.g., standard operating procedures governing the selection and use of respirators).
- Regular worker training.
- Routine air monitoring and work surveillance.
- Routine maintenance, proper storage, inspection, cleaning, and evaluation of respirators.
- Testing of each respirator while it is worn by an individual to confirm that the protection factor expected for that class of respirators is being achieved.

(2) Selecting the appropriate respirator depends on the specific contaminants and their concentration in the worker's breathing zone. Before a respirator can be selected, an assessment of the work environment is usually necessary to determine the concentration of the specific metal fume and other particulates, gases, or vapors that may be present. Until an environmental assessment is completed, however, the employer should review the precautionary labels on filler metals, electrodes, and flux materials and make a best estimate of the appropriate class of respirators. Only the most protective types of respirators shall be used if exposure to a carcinogen is likely (e.g., cadmium, chromium, nickel contained in filler metals, electrodes, fluxes, or during stainless steel welding) or confirmed by environmental measurements. Respirators shall be selected in accordance with the most recent edition of the NIOSH Respirator Decision Logic [NIOSH 1987].

(3) When workers are exposed to a combination of contaminants in different physical forms, combination cartridge and particulate filter air purifying respirators may be acceptable under specific

conditions as long as none of the agents are considered to be carcinogenic. In such cases, a qualified individual shall select the respirator, taking into account the specific use conditions, which include the interaction of contaminants with the filter medium, space restrictions caused by the work location, and the use of welding helmets or other face and eye protective devices.

(4) A self-contained breathing apparatus or a supplied-air respirator with an auxiliary self-contained breathing apparatus shall be used when welding in confined spaces. Such welding may reduce ambient oxygen concentration, especially if an inert-gas, shielded-arc welding process is used.

(d) Hearing Protection

The employer shall provide and require the use of ear protectors whenever there is a potential for noise levels to exceed the NIOSH REL or OSHA PEL.

- Insert-type ear protectors shall be fitted by a person trained in this procedure.
- Inspection procedures shall be established to assure proper issuance, maintenance, and use of ear protectors.
- Workers shall be trained in the proper care and use of all ear protectors.

Section 6 - Informing Workers of the Hazard

(a) Frequency of Hazard Communication

Before assignment and at least annually thereafter, the employer shall provide information about workplace hazards to all workers assigned to work in welding areas. In addition, employers shall follow the OSHA regulations in 29 CFR 1910.1200, Hazard Communication.

(b) Training Program

Hazard information shall be disseminated through a training program that describes how a task is properly done, how each work practice reduces potential exposure, and how it benefits the worker to use such a practice. Workers who are able to recognize hazards and who know how to control them are better equipped to protect themselves from unnecessary exposure. Frequent reinforcement of the training and supervision of work practices are essential.

(c) File of Written Hazard Information

Appropriate written hazard information and records of training shall be kept on file and made readily available to workers. This information shall include the following:

(1) Identification of the various health hazards, including specific metal fumes, gases released or formed by the processes, heat, noise and vibration, optical radiation, and X-radiation.

(2) Instructions for preventing accidents such as explosion, fire, and electrocution.

(3) An explanation of the hazards of working in confined spaces, including the risk of oxygen-deficient atmospheres, exposure to toxic or explosive chemicals, and the potential for heat stress.

(4) An explanation of the potential health effects of exposure to chemical and physical agents generated by welding (e.g., a warning of the increased cancer risk for workers exposed to carcinogens or fumes and gases during stainless steel welding).

(5) Information on precautionary measures for minimizing hazards, including work practices, engineering controls, and personal protective equipment.

(6) A description of the environmental and medical surveillance procedures and their benefits.

(d) Instruction about Sanitation

Workers shall also be instructed about their responsibilities for following proper sanitation procedures to protect their own health and safety and that of their fellow workers.

(e) Tobacco Use

Workers should be counseled against the use of tobacco products.

Section 7 - Engineering Controls and Work Practices

(a) Engineering Controls

The following engineering controls shall be used whenever welding is performed, unless they can be demonstrated to be infeasible.

(1) Optical Radiation

Welding shall be performed in booths or screened areas constructed of materials that are noncombustible, opaque, and minimally reflective to light in the range of 200 to 3,000 nanometers (nm). The booths and screens shall be arranged in a manner that does not restrict ventilation. Such equipment shall conform to the requirements of 29 CFR 1910.252(f)(1)(iii), Screens.

(2) Chemicals (Gases, Fumes, and Particulates)

Fixed-station local exhaust ventilation shall be used whenever possible (e.g., at the workbench). In some situations where fixed local exhaust is not feasible, a movable hood with a flexible duct may be used. For gas-shielded arc welding processes, contaminants can be removed by means of a low-volume, high-velocity exhaust (extracting gun).

General ventilation may be necessary where local exhaust ventilation cannot be used; it may also be used to supplement local exhaust ventilation.

When exhaust ventilation systems are used to control emissions, the following requirements shall apply:

- Exhaust hoods and ductwork shall be constructed of fire-resistant materials.

- Ventilation systems shall be equipped with alarms, flowmeters, or other devices to indicate malfunction or blockage of the systems. These systems shall be inspected at the beginning of each shift to ensure their effectiveness.

- The ventilating airflow shall be directed to carry contaminants from the process away from the breathing zone of the process operator or other workers. For local exhaust systems, this usually entails placement of the fume source between the operator and the face of the exhaust duct.

- The hood design, capture velocity, and flow rate must be chosen to capture the emissions effectively.

- Clean make-up air shall be provided in accordance with 29 CFR 1910.252(f)(4)(i).

- Local exhaust systems used to control welding fumes shall have in-line duct velocities of at least 3,000 feet per minute (fpm) to prevent particulates from settling in horizontal duct runs.

- Canopy hoods may be used under limited conditions. For example, they may be advisable for collecting the heated fumes from automated welding operations and preventing their dissipation into the general work environment. If a canopy hood is used, however, the worker must not work directly over the welding process and there must be no cross currents beneath the hood.

- Cooling fans shall be considered only when local exhaust is not possible (e.g., remote work areas or outdoor work settings). Cooling fans can remove welding fumes from the breathing zone when properly placed at the side of the worker, but their use is rather limited and they may cause dispersion. Any use of a cooling fan at an indoor worksite requires supplemental general ventilation.

(3) X-Rays

Electron beam welding processes shall be enclosed and shielded with lead or other suitable materials of sufficient mass to prevent the emission of X-rays. All doors, ports, and other openings shall be checked and maintained to ensure that they have proper seals that prevent X-ray emission.

(4) Oxyfuel Equipment

Oxyfuel equipment for welding shall be installed, maintained, and used in a manner that prevents leakage, explosion, or accidental fire. Such equipment shall conform to the requirements of 29 CFR 1910.252(a), Installation and Operation of Oxygen-Fuel Gas Systems for Welding and Cutting.

(5) Fires or Electric Shocks

Arc and resistance welding equipment shall be installed, maintained, and used in a manner that prevents fire or electric shock. Such equipment shall conform to the requirements of 29 CFR 1910.252(b), Application, Installation, and Operation of Arc Welding and Cutting Equipment, and to 29 CFR 1910.252(c), Installation and Operation of Resistance Welding Equipment.

(b) Work Practices

Work practices shall, at a minimum, conform to 29 CFR 1910.251-254, Welding, Cutting, and Brazing. Specific work requirements include the following:

(1) Workers shall use welding helmets. Hand-held screens shall be prohibited during welding.

(2) Workers shall adhere to the following safety procedures:

- Workers shall observe the fire precautions prescribed in 29 CFR 1910.252(d).
- Workers shall not conduct welding on materials that may produce toxic pyrolysis or combustion products.
- Workers shall use personal protective clothing and equipment selected specifically for the hazard. Whenever possible, the workpieces to be welded should be positioned to minimize worker exposure to molten metal, sparks, and fumes.

Section 8 - Sanitation

(a) Food, Cosmetics, and Tobacco

The storage, preparation, dispensing, or consumption of food or beverages; the storage or application of cosmetics; and the storage or use of all tobacco products shall be prohibited in areas where welding is conducted.

(b) Handwashing

The employer shall provide handwashing facilities and encourage workers to use them before eating, smoking, using the toilet, or leaving the worksite.

(c) Cleaning of Clothes and Equipment

Protective clothing, equipment, and tools shall be cleaned periodically.

(d) Toxic Waste Disposal

Toxic wastes shall be collected and disposed of in a manner that is not hazardous to workers or others.

(e) Cleanup of Work Area

The work area shall be cleaned at the end of each shift (or more frequently if needed) using vacuum pickup. Dry sweeping or air hoses shall not be used to clean the work area. Collected wastes shall be placed in sealed containers with labels that indicate the contents. Cleanup and disposal shall be conducted in a manner that prevents worker contact with wastes and complies with all applicable Federal, State, and local regulations.

(f) Showering and Changing Facilities

Workers shall be provided with and advised to use facilities for showering and changing clothes at the end of each work shift.

(g) Flammable Materials

Work areas shall be kept free of flammable debris. Flammable work materials (rags, solvents, etc.) shall be stored in approved safety containers.

Section 9 - Exposure Monitoring

(a) General

(1) Exposure monitoring shall be conducted as specified in parts (b), (c), and (d) of this section for all workers performing welding and for all other workers who may be occupationally exposed through their proximity to these processes.

(2) Air from the worker's breathing zone shall be sampled for fumes and gases. Samples for workers performing welding shall be collected in the welding helmet; samples for other workers shall be collected as close to the mouth and nose as possible.

(3) Results of all exposure monitoring (e.g., of fumes, gases, and physical agents) shall be recorded and retained as specified in Chapter I, Section 10 of this document.

(b) Determination of Exposures

(1) The employer shall conduct industrial hygiene surveys to determine whether exposures to any air contaminant exceed the applicable exposure limit (see definition in Section 1(b)).

(2) The employer shall keep records of these surveys as defined in Chapter I, Section 10 of this document. If the employer concludes that exposures are below NIOSH exposure limits, the records must show the basis for this conclusion.

(3) Surveys shall be performed semiannually or whenever changes in work processes or conditions are likely to produce increased concentrations of any air contaminant.

(c) Routine Monitoring

(1) If the occupational exposure to any air contaminant is at or above the exposure limit (see definition in Section 1(b)), a program of personal monitoring shall be instituted to permit calculation of each worker's exposure. Source and area monitoring may be a useful supplement to personal monitoring. In all personal monitoring, samples representative of a time-weighted average (TWA) and/or ceiling exposure (depending on the specific agent) shall be collected in the breathing zone of the worker. Sampling and analysis shall be done in accordance with the methods given in Chapter VI, Table VI-1. For each determination of an occupational exposure, a sufficient number of samples shall be collected to characterize each worker's exposure during each work shift. Though not all workers have to be monitored, sufficient samples should be collected to characterize the exposures of all workers who may be potentially exposed. Variations in work habits and production schedules, worker locations, and job functions shall be considered when deciding on sampling locations, times, and frequencies.

A worker exposed to any specific fume or gas at concentrations below its exposure limit shall be monitored at least once every 6 months; more frequent monitoring may be indicated by a professional industrial hygienist.

If a worker is exposed to any specific fume or gas in excess of the exposure limit, controls shall be initiated as specified in Chapter I, Section 7 of this document. In addition, the worker shall be notified of the exposure and of the control measures being implemented. The worker's exposure shall be evaluated at least once a month. Such monitoring shall continue until two consecutive determinations at least 1 week apart are below the exposure limit. After that point, monitoring shall be conducted at least semiannually or whenever the work process or conditions change.

(d) Physical Agent Monitoring

(1) Exposure to UV radiation shall be prevented by means of a management control program. The program shall require the use of barriers wherever possible. Where barriers cannot be used, workers shall use personal protective devices, including proper clothing, sunscreens with a sun protection factor (SPF) $\geq$15, and body and face shields. The use of barriers and protective devices shall be evaluated every month.

(2) Noise exposures shall be evaluated for all workers performing welding. Plasma arc, metal spraying, and arc air gouging processes are likely to result in excessive noise exposures. Employers shall meet the requirements of 29 CFR 1910.95(c), Hearing Conservation Program, whenever a worker's noise exposure is $\geq$85 decibels measured on the A scale (dBA) as an 8-hr TWA. All monitoring instruments shall conform to the requirements of 29 CFR 1910.95(d)(2), Monitoring; they shall have a Type II microphone at a minimum. Such noise monitoring surveys must be repeated whenever a change in the work process or environment increases the potential for worker noise exposures.

(3) Electron beam welding equipment shall be surveyed periodically to detect any leakage of X-radiation. A preliminary survey shall be conducted at the time of installation while operating at maximum current and voltage levels. Subsequent surveys should be made whenever the equipment is moved or repaired. Operators of such equipment shall use film badges or some other means of monitoring X-ray exposure.

(4) Environmental heat exposures shall be assessed whenever the potential exists for workers to be exposed to elevated ambient temperatures (e.g., when working in confined spaces or subjected to poor ventilation). Monitoring practices shall be those specified in Criteria for a Recommended Standard....Occupational Exposure to Hot Environments [NIOSH 1986].

Section 10 - Recordkeeping

(a) Exposure Monitoring

The employer shall establish and maintain an accurate record of all exposure measurements as required in Chapter I, Section 9 of this document. These records shall include the name of the worker being monitored, social security number, duties performed and job locations, dates and times of measurements, sampling and analytical methods used, type of personal protection used (if any), and number, duration, and results of samples taken.

(b) **Medical Monitoring**

The employer shall establish and maintain an accurate record for each worker subject to the medical monitoring specified in Chapter I, Section 3 of this document.

(c) **Record Retention**

In accordance with the requirements of 29 CFR 1910.20(d), Preservation of Records, the employer shall retain the records described in Chapter I, Sections 3, 6, and 9 of this document for at least the following periods:

(1) Thirty years for exposure monitoring records, and

(2) Duration of employment plus 30 years for medical surveillance records.

(d) **Availability of Records**

(1) In accordance with 29 CFR 1910.20, Access to Employee Exposure and Medical Records, the employer shall upon request allow examination and copying of exposure monitoring records by the subject worker, the former worker, or anyone having the specific written consent of the subject or former worker.

(2) Any medical records that are required by this recommended standard shall be provided upon request for examination and copying to the subject worker, the former worker, or anyone having the specific written consent of the subject or former worker.

(e) **Transfer of Records**

The employer shall comply with the requirements for the transfer of records as set forth in 29 CFR 1910.20(h), Transfer of Records.

II. HAZARD IDENTIFICATION

A. Workplace Monitoring and Analytical Methods

An occupational health program should include methods for thoroughly identifying and assessing all potential hazards if it is to protect welders from the adverse health effects of chemical and physical agents in their work environment. Information provided by monitoring and analysis is needed to determine whether controls (e.g., engineering controls or protective clothing) are necessary, what types of tests should be conducted in a medical monitoring program, what information should be included in a worker training program, what types of warning signs should be posted, and what types of work practices may be required to protect the health of workers. Routine exposure monitoring is also an important part of this program because it gauges the effectiveness of controls.

1. Airborne Contaminants

Routine air monitoring of the workplace helps to determine whether a worker is exposed to any individual chemical at or above its exposure limit. These data must be obtained for all workers involved in welding activities and for all other persons working near welding sites. If a worker's exposure can be accurately characterized, and if concentrations of specific agents are found to be below their exposure limits (or below their action limits if the agents have established NIOSH RELs), further characterization of the work environment is not needed as long as the process or work conditions do not change. No safe exposure concentration has been established for chemicals that NIOSH has identified as potential occupational carcinogens.

An effective air monitoring program should include the following components to accurately assess each worker's exposure:

- A procedure to assess the worker's potential for exposure. This procedure should include collection of data on the types of materials being used (e.g., welding rods and fluxes) and the composition of the base metals,

- Knowledge of air sampling and analytical method(s) required to determine concentrations of airborne chemical and physical agents, and

- Information on the number of workers potentially exposed and the duration of their exposure.

a. **Determining the Potential for Exposure**

The first step in determining the potential for exposure to a specific agent is the preparation of a hazard inventory. This inventory should include information on the type of welding process that will be performed, the possible chemical and physical agents that may be encountered, and the composition of the base metal, coatings on the metal, fillers, and fluxes. This initial assessment should include a review of all precautionary labels on containers of filler metals, electrodes, and flux materials and any material safety data sheets. (Refer to Chapter III, B [Potential for Exposure] in the full-length criteria document, for a more detailed description of contaminants that may be encountered during welding.)

After an initial assessment of potential airborne exposures, employers should identify workers whose exposures to a specific agent may be at or above its exposure limit (or action limit if the agent has an established NIOSH REL). To determine which workers may be at increased risk of exposure, the following work conditions should be evaluated: the location of the welding process with respect to the worker(s), frequency of the welding being performed, the use of engineering controls, and the type of work practices employed. If some uncertainty exists about a worker's exposure (regardless of job title), the worker should be included in the air monitoring program, at least initially.

b. **Sampling Strategy (Location, Number, and Frequency of Sampling)**

The following subsections provide some basic criteria for establishing and implementing a sampling strategy.

(1) Sampling Location

The sampling location is important in achieving an accurate characterization of the suspected exposure. The preferred sampling location is within the breathing zone of the worker and is referred to as a personal sample. The concentration of fumes or gases in the welder's breathing zone for a given process varies depending on the specific work practices of the welder and the type of exhaust ventilation used. For example, if a welder leans over the work, exposure for that worker will be greater than for a welder in an upright position. Moreton et al. [1975] reported that exposure concentrations varied by a factor of six among welders who performed the same task but used different work practices. In addition, the concentration of airborne contaminants typically varies as a function of distance from the worksite. The type of ventilation, convective drafts, and location of the operation further increase the variability of contaminant concentrations with distance from the source.

If personal samples are collected on a worker wearing a welding helmet, the inlet to the sampling device should be correctly positioned within the helmet. The helmet reduces to some degree the amount of contaminant in the breathing zone. Johnson [1959] sampled outside and inside a welding helmet simultaneously during production welding. Concentrations of iron fumes were compared for the two sample locations. The ratio of outside to inside concentrations ranged from 1.03:1 to 7.55:1, with an average of 3.5:1. Based on this and similar experimental studies, the American Welding Society (AWS) Standard F1.1-76, "Method for Sampling Airborne Particulates Generated by Welding and Allied Processes," specifies that air samples should be taken within the welding helmet 50 millimeters (mm) to the left or right of the welder's mouth. In a similar study measuring the performance of full-facepiece respirators, Myers and Hornung [1987] found that sampling errors in the facepiece were minimized by placing the inlet of the sampling probe to within 1/2 to 3/4 inch (in.) of the wearer's mouth.

Because welding emissions often consist of fumes and gases, different sampling media are often required. However, space is restricted in the welding helmet, and wearing several air sampling instruments can cause discomfort. Thus a given worker may have to be monitored over a period of several days, or different types of samples may have to be collected on various workers at the same worksite.

(2) Number of Samples Required

Once the sampling location has been identified, employers should select the number and type of workers to be sampled by considering which workers have the highest potential for exposure and which workers are potentially exposed despite working some distance from the welding process. For a more detailed discussion on the selection of workers and a strategy for sample collection, consult the NIOSH Occupational Exposure Sampling Strategy Manual [Leidel et al. 1977]. This manual also provides guidance on the length of time needed for sample collection, number of samples required for statistical validity, and the scheduling of sample collection (i.e., on one or multiple days) to accurately define workers' exposures.

(3) Sampling Frequency

Unless welding is performed under production-line conditions, sampling should be conducted at frequent intervals to characterize exposures adequately and determine the need for controls. However, when the welding process is repetitive (as it is on a production line), exposure conditions may be characterized and quantified by an initial sampling survey. It can be assumed that conditions will remain relatively constant during future welding activities if there is no change in the process or type of welding. Under these circumstances, routine sampling should not be necessary. This strategy applies only when the survey results indicate that workers are not being exposed to any agent at or above its exposure limit (or action limit if the agent has an established NIOSH REL). With these survey results, no further sampling is necessary as long as no change occurs in the conditions that existed during sampling.

Unfortunately, it is not always possible to note when conditions change. For example, if debris accumulates in the ventilation system, the collection efficiency of the system may decrease, and workers' exposures could increase without any visible signs of change. Although this type of potential problem may not necessitate routine air sample monitoring, it does require periodic examination of the ventilation system to ensure that it is operating at optimum efficiency. If the potential exists for any condition to change (e.g., malfunction of ventilation system) without apparent warning, then a routine monitoring program should be implemented and continued until all such conditions can be standardized. For a more detailed discussion on determining the need for additional sampling, consult the NIOSH Occupational Exposure Sampling Strategy Manual [Leidel et al. 1977].

c. Analytical Methods

Analytical methods for assessing samples of most welding emissions have been developed by NIOSH and are listed in Table II-1. Methods for monitoring physical agents are presented in Table II-2.

2. Physical Agent Monitoring

Physical hazards associated with welding include electromagnetic radiation, X-radiation, and noise. The following guidance is provided to assist in the initial assessment of these potential hazards.

a. Monitoring UV Radiation Levels

Quantifying exposure to optical radiation is difficult, and the NIOSH criteria document on radiation [NIOSH 1972b] does not include specific recommendations for monitoring UV radiation. The following guidelines are provided to assist in the recognition and control of any potential exposure to UV radiation.

Many welding processes generate radiation from the entire UV spectrum or from parts of the UV spectrum. Most commercially available UV measuring devices (with the exception of the thermopile) are wavelength selective. Thus measuring a welder's exposures to UV radiation can be difficult. Other problems in accurately measuring worker exposures include measurement errors caused by water vapor in the air, errors caused by the directionality of exposure meters, reflection errors, and equipment problems such as solarization and aging of lenses and other components [NIOSH 1972a].

Table II-1.--NIOSH analytical methods for chemicals associated with welding processes

Hazard	NIOSH analytical method number[a]
Acetylene	None
Arsenic, inorganic	7900, 7300
Asbestos	7400
Beryllium	7102, 7300
Cadmium	7048, 7300, 7200
Carbon dioxide	S249
Carbon monoxide	S340(4)
Chromium(VI)	7600 (Cr VI); 7024, 7200, 7300 (other chromium)
Cobalt	7027, 7300
Copper fume	7029, 7200, 7300
Fibrous glass	0500, 7400
Fluorides, inorganic	7902
Iron oxide fume	7200, 7300
Lead, inorganic	7082, 7300
Magnesium oxide fume	7200, 7300
Manganese	7200, 7300
Molybdenum	7300
Nickel, inorganic and compounds	7200, 7300
Nitrogen oxides	6700 (NO_2)
Nuisance dust	0500
Ozone	S8, 153, 154
Phosgene	219
Silver	7200, 7300
Tin, inorganic compounds except oxides	7300
Tungsten and cemented tungsten carbide	7074, 7300
Vanadium	7300
Zinc oxide	7502, 0500, 0600, 7030

[a]NIOSH Manual of Analytical Methods [NIOSH 1984].

Table II-2.--Methods for monitoring physical agents associated with welding processes

Hazard	NIOSH criteria document number*
Hot environments	86-113 (revised) [NIOSH 1986]
Noise	HSM 73-1101 [NIOSH 1972b]
UV radiation	HSM 73-11009 [NIOSH 1972a]

*No NIOSH methods exist for monitoring these physical agents; however, direct-reading instruments may be used to assess workplace exposures, as indicated in NIOSH criteria documents.

Control of UV radiation exposure is best ensured through a management control program that relies on the containment of UV emissions through barriers. Where barriers cannot be used, personal protective devices such as appropriate clothing and barrier creams should be used to protect the skin; proper safety glasses should be worn to protect the eyes.

b. Monitoring X-Radiation

Electron beam welding equipment produces X-rays that are normally contained by the welding chamber. The AWS recommendations outlined in F2.1-78, "Recommended Safe Practice for Electron Beam Welding and Cutting" [AWS 1978], specify that periodic surveys be made to detect any leakage of X-radiation. The electron beam should be grossly unfocused and aimed at a tungsten target. A preliminary assessment of the equipment should be made while it is operating at maximum current and voltage levels to detect leakage. Thereafter, periodic surveys can be made when the equipment is moved or repaired. Film badges or some other means of X-ray exposure monitoring should be provided for equipment operators.

c. Monitoring Noise Levels

Excessive noise may be produced in a number of welding and allied processes including plasma arc, metal spraying, and arc air gouging processes. The potential for a given process to generate excessive noise can quickly be determined using a sound level meter with an A-weighted scale and a type II microphone. However, these meters do not accurately measure impact noise.

Operations that generate significant noise levels during a full work shift require a comprehensive exposure evaluation. With the exception of routine "assembly line" operations, where sound level meters can be used to characterize exposures, most processes are best evaluated using dosimeters. Also, an octave band analysis can be useful in determining the source and frequency of the noise so that appropriate sound-absorptive materials or a barrier for controlling the path of the sound can be selected. The NIOSH criteria document on noise [NIOSH 1972b] discusses equipment and procedures for monitoring noise levels, along with recommendations for reducing exposures and implementing a hearing conservation program.

3. Biological Monitoring

Biological indicators may be useful for assessing human exposures to certain contaminants in the welding environment. Further information may be found in Section B,2 of this chapter (Biological Monitoring).

B. Medical Monitoring

Workers exposed to chemical and physical agents associated with welding processes are at risk of suffering adverse health effects. The respiratory system, eyes, and skin require particular attention during medical examinations conducted for preplacement, periodic monitoring, emergencies, or employment termination.

Medical monitoring as described below should be made available to all workers. The employer should provide the following information to the physician responsible for the medical monitoring program:

- Any specific requirements of the applicable OSHA standard or NIOSH recommended standard
- Identification of and extent of exposure to physical and chemical agents that may be encountered by the worker
- Any available workplace sampling results that characterize exposures for job categories previously and currently held by the worker
- A description of any protective devices or equipment the worker may be required to use
- The composition and toxic properties of the materials used in welding
- The frequency and nature of any reported illness or injury of a worker

1. Medical Examinations

The objectives of a medical monitoring program are to augment the primary preventive measures, which include industrial hygiene monitoring of the workplace, the implementation of engineering controls, and the use of proper work practices and personal protective equipment. Medical monitoring data may also be used for epidemiologic analysis within large plants and on an industry-wide basis; they should be compared with exposure data from industrial hygiene monitoring.

The preplacement medical examination allows the physician to assess the applicant's functional capacity and, insofar as possible, to match these capabilities with the physical demands and risks of the job. Furthermore, it provides baseline medical data that can be compared with any subsequent health changes. This preplacement examination should also provide information on prior occupational exposures.

The following factors should be considered at the time of the preplacement medical evaluation and during ongoing medical monitoring of the worker: (a) exposure to chemical and physical agents that may exert independent and/or interactive adverse effects on the worker's health (including exacerbation of certain preexisting health problems and synergism with nonoccupational risk factors such as cigarette smoking), (b) ancillary activities involved in welding (e.g., climbing and lifting), and (c) potentially hazardous characteristics of the worksite (e.g., confined spaces, heat, and proximity to hazards such as explosive atmospheres, toxic chemicals, and noise). The specific types of information that should be gathered are discussed in the following subsections.

a. Preplacement Examination

(1) Medical History

The medical history should include information on work, social activities, family, and tobacco-smoking habits [Guidotti et al. 1983]. Special attention should be given to any history of previous occupational exposure to chemical and physical agents that may be potentially hazardous.

(2) Clinical Examination

The preplacement examination should ascertain the worker's general fitness to engage in strenuous, hot work. Welding processes entail the use of equipment that is often heavy and that may generate potentially harmful levels of UV radiation, heat, noise, fumes, and gases. The preplacement examination should be directed toward determining the fitness of the worker to perform the intended job assignment.

Appropriate pulmonary and musculoskeletal evaluation should be given to workers whose jobs may require extremes of physical exertion or stamina (e.g., heavy lifting), especially those who must wear personal respiratory protection. Because the standard 12-lead electrocardiogram is of little practical value in monitoring for nonsymptomatic cardiovascular disease, it is not recommended. More valuable diagnostic information is provided by physician interviews of workers that elicit reports of the occurrence and work-relatedness of angina, breathlessness, and other symptoms of chest illnesses. Special attention should also be given to workers who require the use of eye glasses; to assure that these workers must be able to wear simultaneously any equipment needed for respiratory protection, eye protection, and visual acuity, and they must be able to maintain their concurrent use during work activities.

Specific welding processes entail potential exposure to diverse chemical agents known to cause specific occupationally related adverse health effects. These are known as sentinel health events (occupational), or SHE(O)s [Rutstein et al. 1983]. For example, heating of metals with low-boiling points (such as zinc and cadmium) may result in metal fume fever. Exposure to cadmium fumes may result in delayed onset of pulmonary edema and may lead to pulmonary fibrosis and cancer. Nickel and chrome are both found in stainless steel and may cause allergic sensitization as a result of an acute exposure or cancer as a result of chronic exposure. Welding processes that involve the use of flux may generate irritating concentrations of fluorides. Welding on painted metal may result in exposure to lead or other chemical agents, and welding on materials cleaned with a chlorinated solvent may cause photodecomposition of the solvent with resulting exposure. In addition, the worker's duties may be performed in proximity to unrelated operations that generate potentially harmful exposures (e.g., asbestos or cleaning or degreasing solvents). The physician must be aware of these potential exposures to evaluate possible hazards to the individual worker.

(3) Special Examinations and Laboratory Tests

A pulmonary function test (PFT) and a 14- by 17-in. (36- by 43-cm) postero-anterior chest radiograph should be taken and kept as part of the worker's medical record [American Thoracic Society 1982]. The preplacement chest radiograph and PFT gives the physician objective information with which to assess a worker's fitness for a specific job; it may also prevent confusion or misinterpretation of any subsequent lung tissue changes.

The International Labour Office (ILO) stresses the importance of radiographic technique in the detection of early pneumoconiosis. High-speed and miniature films are not recommended. Films should be interpreted using the current recommendations of the ILO [ILO 1980]. Classification of films should be made by NIOSH-certified B readers [Martin 1985]. Although the short classification may be useful for clinical purposes, films that are obtained in a workplace program of medical monitoring for respiratory hazards must be read and recorded by the complete classification [Martin 1985].

Preplacement audiograms of all workers are recommended, since welders, brazers, and thermal cutters may be exposed to noise intensities exceeding prescribed levels.

b. Periodic Medical Examination

A periodic medical examination should be conducted at least annually or more frequently, depending on age, health status at the time of a prior examination, and reported signs or symptoms associated with exposure to welding emissions. The purpose of these examinations is to detect any work-related changes in health at an early stage. The physician should note any trends in health changes revealed by epidemiologic analyses of examination results. The occurrence of an occupationally related disease or other work-related adverse health effects should prompt an immediate evaluation of industrial hygiene control measures and an assessment of the workplace to determine the presence of a previously unrecognized or potential hazard.

The physician's interview with the worker is an essential part of a periodic medical examination. The interview gives the physician the opportunity to learn of changes in (a) the type of welding performed by the worker, (b) metals and/or fluxes being used, (c) the work setting (e.g., confined spaces), and (d) potentially hazardous workplace exposures that are in the vicinity of the worker but are not attributable to the worker's on-the-job activities.

Because radiographic abnormalities may appear before pulmonary impairment is clinically manifested or otherwise detectable, periodic chest radiographs are routinely recommended for monitoring workers exposed to fibrogenic respiratory hazards [American Thoracic Society 1982]. However, the chest radiograph may not distinguish between a relatively benign disease such as siderosis (caused by iron oxide exposure) and a disease that may be of greater medical importance such as pneumoconiosis.

Under ordinary conditions, chest radiographs may be obtained for workers at 1- to 5-year intervals, depending on the nature and intensity of specific exposures and related health risks. Workers with 10 years or more of exposure and workers previously employed in dusty jobs may require chest radiographs at more frequent intervals. These intervals may be changed as called for by other regulatory requirements or at the discretion of the examining physician. For example, a previous radiograph (e.g., one taken at the time of hospitalization) may be substituted for one of the periodic chest radiographs if it is made available and is of acceptable quality. If a worker has radiographic evidence of pneumoconiosis or spirometric/symptomatic evidence of pulmonary impairment, the physician should counsel the worker and employer about the potential risks of further exposure and the benefits of removing the worker from exposure. Smokers should be counseled about how smoking may enhance the adverse effects of other respiratory hazards.

Epidemiologic studies suggest an association between exposure to airborne welding fumes and gases and an excessive risk of lung cancer. Because routine chest radiographs and sputum cytology are inadequate for detecting bronchogenic carcinoma early enough to alter the course of the disease, they are not currently recommended as part of regular medical monitoring for lung cancer in workers.

During the periodic medical examination of individual welders, the physician should reexamine the skin, eyes, and other organ systems at risk to note changes from the previous examination. The physician should direct special attention to evidence of burns and effects from exposure to UV radiation and solvents. This evidence may suggest inadequate industrial hygiene control measures, improper work practices, or malfunctioning equipment (e.g., exposure to metal spatter, flying sparks, UV light flashes, or degreaser solvents). In addition, the physician should be vigilant for musculoskeletal morbidity attributable to ergonomic problems caused by inadequate worker training on the handling of equipment or by improper working position (e.g., kneeling and overhead welding).

When welders are exposed to agents for which there is an existing OSHA standard or for which NIOSH has recommended medical monitoring, physicians should refer to the appropriate standard or recommendation for guidance on specific medical examinations. (See Appendix B in the full-length criteria document for published sources of NIOSH RELs for hazardous agents associated with various welding operations.)

Hazardous agents that are commonly associated with welding processes are listed in Table II-3 along with their potential toxic effects and recommendations for additional tests.

2. Biological Monitoring

Urinary or blood concentrations of lead, cadmium, chromium, and aluminum, and urinary concentrations of fluoride ions may be useful biological indicators of worker exposure to welding emissions. Several studies have correlated exposures to welding fumes containing chromium [Tola et al. 1977; Mutti et al. 1979; Kalliomaki et al. 1981; Sjogren et al. 1983a], aluminum [Sjogren 1983b; Mussi et al. 1984], or fluoride [Krechniak 1969; Pantucek 1975] with their urinary or blood concentrations. However, biological monitoring may not be sensitive enough to use as a primary monitoring measure. For example, Tola et al. [1977] found no increase in urinary chromium concentrations when environmental chromium concentrations were within the NIOSH REL. Biological monitoring has the potential for assessing total exposure when the work load (physical activity) and the routes of exposure are taken into account. Mutti et al. [1979] and Pantucek [1975] showed that urinary levels of chromium and fluoride can provide information on either current exposure or body burden, depending on the timing of the sample collection. Schaller and Valentin [1984] concluded that aluminum concentration in serum seemed to be an indicator of body burden, and that aluminum concentration in urine seemed to be an indicator of current exposure. Thus biological monitoring may be a useful adjunct for detecting accidental exposure or a failure of primary control measures.

Table II-3.--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a] Short-term	Long-term	Supplemental tests[b]
Gases:			
Acetylene[c]	Anesthesia (at high concentration)	N/A	
Carbon monoxide	Headache, nausea, dizziness, collapse, death	Cardiovascular effects (cardiomyopathy, exacerbates existing coronary artery disease)	Carboxyhemoglobin (COHb)
Oxides of nitrogen	Pneumonitis, pulmonary edema	Chronic bronchitis, emphysema, pulmonary fibrosis	
Ozone	Respiratory tract irritation (cough, chest tightness), dryness of mucous membranes, headache, sleepiness, fatigue, pulmonary edema, wheezing	Pulmonary insufficiency	
Phosgene	Pneumonitis, pulmonary edema	Emphysema, pulmonary fibrosis	
Metals:			
Arsenic	Dermatitis, gastrointestinal symptoms (nausea, vomiting, diarrhea)	Cancer (lung, lymphatic, skin), skin (hyperpigmentation, palmar/plantar warts, hyperkeratosis), anemia, leukopenia, cardiomyopathy, hepatic cirrhosis, peripheral neuritis (numbness, weakness, ataxia)	
Beryllium	Skin (ulcers, dermatitis); conjunctivitis; rhinitis, pharyngitis, tracheobronchitis, chemical pneumonitis	Cancer (lung), pulmonary symptoms (cough, chest pain, cyanosis), systemic weakness, enlargement of liver and spleen	

(continued)

See footnotes at end of table.

Table II-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Cadmium	Pulmonary edema (cough, dyspnea, chest tightness), nasal irritation & ulceration	Cancer (prostate, lung); pulmonary fibrosis, emphysema, honeycomb lung; kidney (proteinuria-low molecular); hematopoietic disturbance (anemia); skeletal (suspected osteomalacia); prostate examination (for workers 40 years and older); anosmia (loss of sense of smell)	Blood urea nitrogen (BUN), complete blood count (CBC), low MW protein in urine
Chromium(VI)[d]	Skin irritation (dermatitis, ulcer), respiratory tract irritation, and effects on nose (epistaxis, septal perforation), eyes (conjunctivitis), and ears (tympanic membrane perforation)	Cancer (lung), kidney and liver damage (suspected)	
Cobalt	Pulmonary sensitization (asthma-like reaction), skin sensitization and irritation	Pulmonary fibrosis, thyroid hyperplasia (possible), polycythemia (possible)	
Copper	Metal fume fever,[e] nasal mucosa irritation	Not known	
Iron		Siderosis (pulmonary deposition of iron dust)	
Lead		Nervous system (neuropathy-extensor palsy), gastrointestinal symptoms (anorexia, constipation, abdominal colic), nephropathy, reproductive effects (on fetal brain), hematopoietic effects (porphyrin metabolism disturbance)	Zinc protoporphyrin (ZPP)

(continued)

See footnotes at end of table.

Table II-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Magnesium	Irritation of nasal mucosa and conjunctiva, metal fume fever[e]	Not known	
Manganese	Chemical pneumonitis	Nervous system (irritability, drowsiness, impotence, muscular rigidity, spasmodic laughing/ weeping, speech & gait disturbances)	
Molybdenum	Irritation of mucous membranes (eyes and nose)		
Nickel	Dermatitis, asthma-like lung disease	Cancer (nose, larynx, and lung), upper and lower respiratory tract irritation (nose bleeding, ulcer and septal perforation), renal dysfunction	
Silver		Argyria or argyrosis (pigmentation of skin and eyes resulting from silver deposition)	
Tin		Stannosis (pneumoconiosis resulting from inhalation of tin oxide)	
Titanium		Pneumoconiosis	
Tungsten[f]	Conjunctivitis, upper respiratory tract irritation (cough, dyspnea)	Extrinsic asthma, pneumoconiosis, diffuse interstitial pneumonitis, fibrosis	
Vanadium	Upper and lower respiratory tract irritation (nose bleeding, cough), conjunctivitis, dermatitis	Chronic bronchitis, emphysema, pneumonia, chronic eye irritation, dermatitis, possible skin and/or respiratory allergy	

(continued)

See footnotes at end of table.

Table II-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Zinc	Metal fume fever[e], skin eruption (oxide pox)	Not known	
Other minerals:			
Asbestos		Cancer (lung, mesothelium), asbestosis, pleural thickening	
Fluorides	Respiratory irritation, gastro-intestinal symptoms	Osteosclerosis, pulmonary insufficiency, kidney dysfunctions[g]	Post-shift urinalysis for F; bone density on periodic chest X-ray; renal functions[g]
Silica		Silicosis	
Physical agents:			
Electricity	Electrocution, burns	Not known	
Hot environments	Heat rash, heat cramps, heat exhaustion (irritability, mental dullness, general weakness), heat stroke	Not known	
Noise	Temporary auditory threshold shift	Hearing loss	
Vibration		Vibration white finger syndrome, Raynaud's phenomenon resulting from localized vibration (tingling numbness, blanching of fingers)	

(continued)

See footnotes at end of table.

Table II-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a] Short-term	Toxic effects[a] Long-term	Supplemental tests[b]
Ionizing radiation	Erythema, radiodermatitis, nausea, vomiting, diarrhea, weakness, bone marrow depression, shock, death	Cancer, cataracts, reproductive effects	Film badges or dosimeters
Ultraviolet radiation (200-400 nm)	Photokeratitis, conjunctivitis, skin erythema and burns	Cancer (skin), cataracts	
Visible light (400-760 nm)	Eye discomfort, fatigue, headache, retinal changes (retinal burn)	Eye discomfort, fatigue, headache, retinal changes (retinal burn)	

[a]Distinction between short-term and long-term effects is not clear-cut and is somewhat arbitrary. Short-term effects are usually the result of acute exposure(s) and may appear immediately to several days or weeks after the exposure. Long-term effects are usually the result of chronic, repeated low-dose exposures extending from several months to many years. However, long-term effects may also include the aftereffects of single or repeated acute exposures.

[b]Tests to be considered at the discretion of the attending physician.

[c]May contain toxic impurities such as arsine, carbon disulfide, carbon monoxide, hydrogen sulfide, and phosphine.

[d]Toxicity information is mostly from chromium plating operation and chromium pigment manufacturing.

[e]Metal fume fever is manifested by fever, chills, cough, joint and muscle pains, and general malaise.

[f]Reports of health effects of tungsten come almost exclusively from the studies of workers exposed to tungsten carbide, which usually contains cobalt.

[g]Renal functions should be evaluated because renal dysfunctions are known to hinder urinary excretion of fluorides.

3. Recordkeeping

Medical records and exposure monitoring results must be maintained for workers as specified in Chapter I, Section 10(c) of this document. Such records must be kept for at least 30 years after termination of employment. Copies of environmental exposure records for each worker must be included with the medical records. These records must be made available to the worker or former worker or to anyone having the specific written consent of the worker, as specified in Chapter I, Section 10(d) of this document.

4. Ergonomic Monitoring

Ergonomic factors in the workplace should be assessed to determine the need for changes in the work environment, equipment, or work practices, or compensating exercises to avoid fatigue or injury. Work postures, vibrating equipment, and moving of heavy objects may all strain the muscles and joints of welders. The static positions frequently used in welding and similar processes may also create ergonomic problems that require analysis. For example, several studies [Herberts and Kadefors 1976; Kadefors et al. 1976; Petersen et al. 1977] have indicated that overhead welding may severely strain the supraspinatus muscle of the shoulder, leading to tendinitis. The movement of workpieces and distribution of workloads may also require study and planning.

Ilner-Paine [1977] reported the use of video monitoring to observe and record the physical exertion of welders while they worked. This technique was useful in diagnosing the causes of back and shoulder pain among shipyard welders. Grandjean [1981] has published additional information on ergonomic principles that can be adapted to jobs typically performed by welders.

III. METHODS FOR PROTECTING WORKERS

A. Informing Workers of Hazards

Employers should provide information about workplace hazards before assignment and at least annually thereafter to all workers assigned to work in welding, brazing, and thermal cutting areas. The OSHA "Hazard Communication" regulation must be followed [29 CFR 1910.1200].

Appropriate written information on hazards (including material safety data sheets) should be kept on file and should be readily available to workers. This information should include a description of the potential health hazards associated with welding (e.g., exposures to noise, vibration, hot metal, optical and X-radiation, and carcinogenic agents such as chromium, nickel, and cadmium) and their possible adverse health effects (e.g., hearing loss, eye injury, burns, and cancer). Workers should also be informed of the most common types of accidents encountered while welding (e.g., explosions, fires, electrocution, and asphyxiation from oxygen-deficient environments). This information should list precautionary measures for minimizing exposure and injury, including work practices, engineering controls, and personal protective equipment. The file should also include a description of the environmental, medical monitoring, and emergency first aid procedures that have been implemented.

Workers should also be instructed about their responsibilities for following proper sanitation procedures to help protect their health and provide for their safety as well as that of their fellow workers.

Information on hazards should be disseminated to all workers through a training program that describes how a task is properly performed, how specific work practices reduce exposures or minimize the risk of injury, and how compliance with these procedures will benefit the worker. Frequent reinforcement of this training and routine monitoring of work practices are essential.

B. Engineering Controls

Because welding processes involve many chemical and physical agents, the hazards they pose cannot always be controlled using current engineering control methods. The processes are usually dynamic, making it difficult to use fixed systems to control exposures. In addition, because of the various characteristics of welding emissions (e.g., fumes, gases, radiation) and the extent and fluctuation of exposure at different processes, the evaluation of exposures is often imprecise, and appropriate controls are difficult to implement. Despite these limitations, engineering controls should be implemented wherever they can minimize the risk of exposure.

1. Optical (Radiation) Hazards

When feasible, welding should be performed in booths or screened areas constructed of one of the following materials: (1) metal, (2) flame-resistant fabric that is opaque to most optical radiation, or (3) transparent colored polyvinyl chloride material that is formulated with a flame retardant and a UV-visible absorber in the range of 200 to 3,000 nm [Tola et al. 1977; Moss and Gawenda 1978; Sliney et al. 1981]. The booths and screens should be arranged so that they do not restrict ventilation. Such equipment must conform to requirements of 29 CFR 1910.252(f)(1)(iii), "Screens."

To minimize ozone production, an opaque shroud should be placed around the arc to minimize the interaction between the optical radiation and the oxides of nitrogen that are generated during the process [Ferry and Ginther 1953; Ditschun and Sahoo 1983].

2. Chemical Hazards (Gases and Fumes)

Gases and fumes generated during welding may necessitate both local and general exhaust ventilation. Although local exhaust ventilation is preferred wherever possible, general ventilation may be used in some cases where the exposures are well characterized and local exhaust ventilation cannot be placed close to the source of emissions [ACGIH 1984].

Ventilation systems should meet the following minimum specifications:

- Exhaust hoods and ductwork should be constructed of fire-resistant materials.
- Systems should be equipped with alarms, flowmeters, or other devices to indicate malfunction or blockage of ductwork.
- The air velocity at the face of the duct should be sufficient to capture the emissions. Hood design should be such that captured emissions are carried away from the breathing zone of the worker.
- Provision should be made for clean make-up air; 29 CFR 1910.252(f)(4)(i) states, "All air replacing that withdrawn shall be clean and respirable."

Various designs of exhaust ventilation systems can provide effective control of fume and gas emissions. In general, local exhaust ventilation works well for welding processes that are conducted at a fixed location such as a workbench, or that are performed on parts of the same size and shape. The degree of effectiveness depends on the distance between the face of the duct inlet and the work, the design of the system, and the flow rate and volume of air exhausted. The use of side baffles or flanges at the duct inlet can increase the capture velocity. The effectiveness of the exhaust ventilation system declines as the distance between the work and the duct inlet increases; a distance of about 9 to 14 in. (24 to 36 cm) is adequate for capturing fumes and gases. After optimizing the design of the duct hood so that it can be placed as close as possible to the work, the flow rate should be adjusted to ensure an effective capture velocity.

When welding is performed at remote sites or with different-sized or very large parts, a flanged hood with a flexible duct may be appropriate. The hood face should be placed at a 0- to 45-degree angle to the work surface and positioned on the side opposite the welder. The use of a flexible duct system requires that the welder be properly instructed to keep the duct hood close to the emission source and to ensure that the duct is not twisted or bent.

An alternative to using an exhaust hood for gas-shielded arc welding processes is to exhaust the emissions by means of an extracting gun. Such extraction systems can reduce breathing zone concentrations by 70% or more [Hughes and Amendola 1982]. These systems require that the gun and shielding gas flow rates be carefully balanced to maintain weld quality and still provide good exhaust flow.

General ventilation can be used to supplement local exhaust ventilation. General ventilation may be necessary where local exhausts cannot be placed close enough to the work to be completely effective. The ACGIH [1984] recommends that where local exhaust cannot be used, 800 cubic feet per minute (cfm) of air be exhausted for every pound of welding rod used per hour.

In-line duct velocities for local exhaust systems that are used to control welding emissions should exceed 3,000 feet per minute (fpm) to prevent particulates from settling in horizontal duct runs. The recirculation of air from local exhaust systems may be appropriate depending on the potential toxicity of the emissions and the efficiency of the filter collection system. The recirculation of air from local exhaust systems is not recommended when the collected emissions are unknown or contain extremely toxic agents. Local exhaust systems must be equipped with flow or vacuum meters or other devices to monitor air flow. These exhaust systems should not be used if their failure to work properly will result in bodily harm before remedial action can be taken [Hughes and Amendola 1982].

For automated welding processes where the worker does not work directly over the source of emissions and there are no cross currents, canopy hoods could be used for collecting heated fumes and gases. When properly placed at the side of the worker and operated at a relatively low velocity, cooling fans can be used in some work environments to remove welding fumes from the breathing zone. Cooling fans have limited use and should be considered only when local exhaust is not possible. The use of a cooling fan in an indoor situation requires supplemental general ventilation.

3. X-Radiation

Electron beam welding processes should be enclosed and shielded with lead or other suitable materials that have a mass sufficient to prevent the emission of X-rays. All doors, ports, and other openings should be checked for X-ray emissions to ensure that all seals are working properly.

4. Noise

During plasma arc welding and cutting and during arc air gouging processes, a water table or other method of similar effectiveness should be used to control noise and airborne emissions.

a. Acoustic Shields

An effective noise reduction of up to 8 decibels (dB) can be achieved by placing an acoustic shield between the worker and the source of the noise [Salmon et al. 1975] usually constructed of safety glass or clear plastic (polycarbonate or polymethyl methacrylate), is placed. This shield is most effective when its smaller dimension (length or width) is at least three times the wavelength of the sound that is contributing to the noise. Thus shields can be effective barriers against the high-frequency sound emitted from the air ejection systems of plasma and metal spray guns.

b. Total Enclosure

A reduction of up to 20 dB can result when the machinery or process is totally enclosed. However, heat buildup is a potential problem and may require the installation of adequate ventilation. Vibration within these enclosures should be isolated from the floor. The enclosure must have ports for possible servicing of electrical, water, oil, and other systems. These ports should be sealed with sound-dampening materials (e.g., 1/8-in. or heavier rubber washers).

c. Other Recommendations

Personal hearing protection devices are recommended if engineering controls cannot maintain worker exposures at 85 dBA as an 8-hr TWA. Ear plugs (molded, foam, or acoustic wool) and earmuffs can significantly reduce a worker's noise exposure.

To determine whether the hearing protection device will be adequate, the manufacturers' data on noise attenuation should be compared with the actual reduction required. Employers can also use one of three methods developed by NIOSH and reported in the <u>List of Personal Hearing Protectors and Attenuation Data</u> [NIOSH 1976]. Additional information on hearing protection devices may be found in the <u>Compendium of Hearing Protection Devices</u> [Lempert 1984]. Extreme care must be taken in using the manufacturers' data, as it represents the maximum protection possible under ideal conditions. In a NIOSH study to determine the noise reduction provided by insert-type hearing protectors, 50% of the workers tested were receiving less than one-half the expected noise attenuation [Lempert and Edwards 1983]. Noise reduction was also less than expected when the Mine Safety and Health Administration (MSHA) conducted a study in which microphones were placed inside and outside the protective cup on muff-type protectors while the workers performed their normal tasks [Bureau of the Census 1984].

Whenever workers are exposed to noise levels exceeding 85 dBA as an 8-hr TWA, the employer must administer a continuing, effective hearing conservation program [29 CFR 1910.95(c)]. The program must include monitoring, worker notification, an audiometric testing program, availability of hearing protectors for workers, record-keeping, and a training program. Hearing protection becomes mandatory when workers' exposures exceed 90 dBA as an 8-hr TWA [29 CFR 1910.95(b)].

5. Oxyfuel Equipment

Ventilation systems and other control devices for oxyfuel equipment should be inspected at least weekly to ensure their effectiveness. Oxyfuel equipment for welding should be installed and maintained in a manner that prevents leakage, explosion, or accidental fire. Such equipment must conform to the requirements of 29 CFR 1910.252(a), "Installation and operation of oxygen-fuel gas systems for welding and cutting."

6. Fire or Electric Shock

Arc and resistance welding equipment should be installed and maintained in a manner that prevents fire or electric shock. Such equipment must conform to the requirements of 29 CFR 1910.252(b), "Application, installation, and operation of arc welding and cutting equipment," and to 29 CFR 1910.252(c), "Installation and operation of resistance welding equipment."

C. Work Practices

The prevention of occupational illness and injury while welding requires the use of well-designed work practices. These include wearing personal protective clothing; using safe work procedures for process operations; practicing good housekeeping, sanitation, and personal hygiene; handling compressed gases safely; and being informed on how to handle emergency situations. Together with engineering controls, such practices can reduce the health risks to workers. At a minimum, work practices must conform to OSHA standards (e.g., 29 CFR 1910.251-254, "Welding, Cutting, and Brazing" [OSHA]). Additional information on proper work practices is available in the ANSI Z49.1 standard, "Safety in welding and cutting" [AWS 1973] and in the National Safety Council's Accident Prevention Manual [McElroy 1980].

1. Specific Work Procedures

The manner in which a worker prepares for and carries out welding processes has a direct bearing on the type and extent of the exposure hazard. For example, Moreton et al. [1975] found that variations in the size of work area, ventilation, and work practices caused welders performing the same welding task to be exposed to breathing zone concentrations of fumes and gases that varied by a factor of up to six.

Other factors that affect the generation of fumes, gases, and optical radiation include the operating current and voltage, the diameter and angle of the electrode, and the type of shielding gas used. Some of these factors may not be up to the worker's discretion to change, and others may depend on product specifications or production schedules.

The type of welding process used on steel can affect fume generation rates. Flux-cored arc and shielded metal arc welding generate many more fumes than gas metal arc and gas tungsten arc welding. When shielded metal arc welding must be used, low-fuming electrodes may be acceptable substitutes for conventional types. The electrical current and the position of the electrode while welding both affect fume generation [Thrysin et al. 1952; Morita and Tanigaki 1977; Pattee et al. 1978]. An increase in the welding current tends to increase the rate of fuming, gas production, and optical radiation emission. Manufacturers of consumable electrodes usually specify a range of amperages that should be used during welding. The welder can minimize emissions by using the lowest acceptable amperage. In addition, holding the electrode as close to the work surface as possible and perpendicular to it will minimize the arc voltage used and thus decrease the rate of fuming [Kobayashi et al. 1976; Pattee et al. 1978].

Pattee et al. [1978] noted that when the contact-tube-to-work distance is increased, a greater metal deposition rate occurs, which in effect decreases the fume generation rate. However, fume rate tends to increase when the polarity is dc+ (i.e., reverse polarity) rather than dc- or ac [Kobayashi et al. 1976; Pattee et al. 1978] or when the thickness of the metal increases [Heile and Hill 1975; Kobayashi et al. 1976; Siekierzynska and Paluch 1972; Ulrich et al. 1977]. The type and moisture content of flux coating used on electrodes also affects the fume generation rate [Kobayashi et al. 1976], as does the composition of the shielding or plasma gas [Pattee et al. 1978].

Special precautions should be taken when working in areas not specifically designed for welding. Such precautions must include (1) observing fire precautions prescribed in 29 CFR 1910.252(d), (2) removing, shielding, or cooling any materials present that may produce toxic pyrolysis or combustion products, and (3) using appropriate personal protective clothing and equipment required for the specific hazard. Whenever possible, the workpieces to be welded should be positioned to minimize worker exposure to molten metal, sparks, and fumes.

2. Confined Spaces

Working in confined spaces can be extremely hazardous as a result of explosive, toxic, or oxygen-deficient atmospheres [NIOSH 1979]. Although a confined space may initially have good air quality, any subsequent welding in this space can cause a rapid buildup of toxic air contaminants, a displacement of oxygen by an inert or asphyxiating gas, or an excess of oxygen that might explode. Only by careful preparation can a worker be assured of working safely within a confined space. A complete set of recommendations for working in a confined space is presented in the NIOSH document Criteria for a Recommended Standard: Working in Confined Spaces [NIOSH 1979]. Some of the more pertinent recommendations are given below.

a. Before workers enter a tank, reaction vessel, ship compartment, or other confined space, a permit entry procedure should be set up. Authorization to permit entry should be assigned to a qualified person, and access should be permitted only when all necessary measures have been taken to protect the worker. The following precautions must be taken before permission is given:

- All pipes, ducts, and power lines connected to the space but not necessary to the operation must be disconnected or shut off. All shutoff valves and switches must be tagged and secured with a safety lockout device.

- Continuous mechanical ventilation must be provided when welding or thermal cutting is done in confined spaces. Oxygen must never be used for ventilation purposes [29 CFR 1910.252].

- Initial air monitoring must be performed to determine the presence of flammable or explosive materials and toxic chemicals, and to determine if there is sufficient or excessive oxygen. Depending on the monitoring results and the adequacy of the mechanical ventilation, continuous monitoring may be necessary during welding. Prohibit entry when tests indicate flammable concentrations greater than 10% of the lower flammable limit.

- Gas cylinders and power sources for welding processes must be located in a secure position outside the space.

- A designated worker must be stationed outside the confined work space to maintain visual and voice contact and to assist or rescue the entering worker if necessary. The designated worker must be equipped with appropriate protective gear and must remain in position throughout the time that any worker is within the enclosed space.

- The worker entering the confined space must be outfitted with a safety harness, a lifeline, and appropriate personal protective clothing and equipment, including a respirator.

- Lifelines must be attached so that the welder's body cannot become jammed in a small exit opening.

- When not in use, torches and other gas- or oxygen-supplied equipment must be removed from the confined space [29 CFR 1910.252(d)(4)(ii)].

- All welders and persons supporting those workers shall be trained in the following areas: emergency entry and exit procedures, use of applicable respirators, first aid, lockout procedures, safety equipment use, rescue procedures, permit system, and good work practices.

The type of respirator required depends on the concentration of oxygen and the contaminants that might be generated. Respirator requirements may range from none to a self-contained breathing apparatus with a full facepiece operated in pressure-demand or positive-pressure mode. Respirators must be selected in accordance with the most recent edition of the NIOSH Respirator Decision Logic [NIOSH 1987].

Even though continuous mechanical ventilation is required during welding processes in confined spaces, initial and continuous environmental monitoring is extremely important. Equipment used for monitoring of fumes and gases should be explosionproof, and continuous monitoring equipment should have an audible alarm or danger-signaling device to alert workers when a hazardous situation develops. All instruments should be calibrated periodically in accordance with the manufacturers' instructions. The results of each calibration must be recorded, filed by the employer, and made available for inspection for 1 year after the calibration date. Monitoring equipment must be reliable and have sufficient sensitivity to clearly identify a hazardous condition.

Oxygen deficiencies are of particular concern when welding in confined spaces. The normal 21% concentration of oxygen in air may be decreased in confined spaces by chemical or biological processes. When oxygen concentrations fall below 16.8% by volume, a worker may have difficulty remaining alert. Whenever the oxygen content falls below 19.5%, appropriate respirators must be used.

NIOSH respirator certification [30 CFR 11] requires that only self-contained breathing apparatuses or supplied-air respirators with auxiliary self-contained breathing apparatuses be used in atmospheres below 19.5% oxygen.

3. Preparation for Work

Before welding is performed in any work area, the worker should be aware of any potentially hazardous materials or conditions that may exist in that area. Before striking an arc or lighting a flame the worker must remove all nearby flammable materials if the piece to be welded or cut is not readily movable. A number of companies have a "permit system" that requires the supervisor's approval before welding is performed [Shell Chemical Company 1974; Toleen 1977]. Before issuing such a permit, the supervisor must check for conformance to OSHA regulations (such as 29 CFR 1910.252) and any specific company rules. Some of the most common company requirements include checking the serviceability of local firefighting equipment, moving all combustible materials at least 35 ft (10.7 m) from the work site, and assigning a worker (equipped with a suitable extinguisher and trained in its use) to perform a fire watch from outside the workspace. Combustibles that cannot be removed should be shielded with a nonflammable material. Shielding should also be provided to cover openings or cracks in floors, walls, and windows to prevent other workers from being exposed to sparks, hot metal and slag, and optical radiation.

The fire watch should be continued for at least 30 min after job completion to guard against smoldering fires. The workpiece and work area should also be free of substances that may be rendered more hazardous by the work. These include any halogenated hydrocarbons in the atmosphere that can be decomposed to phosgene or other harmful products by an arc or a flame [Frant 1974]. Polymer materials may also form hazardous fumes or gases when exposed to heat [Robbins and Ware 1964]. Finally, the worker should be informed of (1) any unusually hazardous constituents of the work materials such as beryllium, cadmium, chromium, nickel, etc., (2) any hazardous coatings such as lead paint, mercury, or zinc, and (3) any precautions and control measures necessary for minimizing potential health risks.

4. Containers

Drums, containers, pipes, jackets, and other hollow structures should be properly prepared and tested before welding [McElroy 1980]. Preparation of hollow structures varies depending on their contents. At a minimum, the following procedures should be undertaken to minimize the risk of accidental injury or exposure to toxic agents: remove all ignition sources; disconnect the structure from any pipes, hoses, or other connections; examine the interior for waste or debris; and cleanse the structure of flammable materials or materials that could produce flammable or toxic vapors upon heating. The appropriate cleaning process for containers depends on the materials present. For many types of materials, an adequate cleaning process consists of steaming the container, washing with caustic soda, and rinsing with boiling water. The container should be dried and inspected. Check for the presence of flammable or toxic gases or vapors. Vent the container to prevent a buildup of pressure in the interior. Further protection may be given by filling the container with water to within an inch or two of the area to be welded or cut, and/or purging the interior of the container with inert gas. Before cutting or welding is permitted, the area must be inspected by the individual responsible for authorizing welding processes [29 CFR 1910.252]. Preferably, such authorization should be in the form of a written permit.

5. Emergencies

The employer should formulate a set of written procedures covering fire, explosion, electrical shock, asphyxiation, and any other foreseeable emergency that may arise in welding processes. All potentially affected workers should receive training in evacuation procedures to be used in the event of fire or explosion. All workers who are involved in welding processes should be thoroughly trained in the proper work practices to reduce the potential for starting fires and causing explosions. Selected workers should be given specific training in first aid, cardiopulmonary resuscitation, and fire control. Procedures should include prearranged plans for transportation of injured workers and provision for emergency medical care. At least two trained persons in every work area should have received extensive emergency training. Necessary emergency equipment, including appropriate respirators and other personal protective equipment, should be stored in readily accessible locations.

D. Personal Protective Clothing and Equipment

1. Clothing

The employer should provide and require the use of protective clothing as follows:

- All welders should wear flame-resistant gauntlet gloves and shirts with sleeves of sufficient length and construction to protect the arms from heat, UV radiation, and sparks. In most cases, wool and leather clothes are preferable because they are more resistant to deterioration and flames than cotton or synthetics. Welders should not wear light-weight, translucent fabrics and fabrics that show severe wear with holes [USAEHA 1984].

- All welders should wear fire-resistant aprons, coveralls, and leggings or high boots.

- Welders performing overhead work should wear fire-resistant shoulder covers (e.g., capes), head covers (e.g., skullcaps), and ear covers.

- Workers welding on metal alloys that contain highly toxic elements (e.g., beryllium, cadmium, chromium, lead, mercury, or nickel), should wear work uniforms, coveralls, or similar full-body coverings that are laundered each day. Employers should provide lockers or other closed areas to store work and street clothing separately. Employers should collect work clothing at the end of each work shift and provide for its laundering. Any clothing treated for fire resistance should be retreated after each laundering. Laundry personnel should be informed about the potential hazards of handling contaminated clothing and instructed on measures to minimize their health risk.

- Employers should ensure that protective clothing is inspected and maintained to preserve its effectiveness. Clothing should be kept reasonably free of oil or grease. Front pockets and upturned sleeves or cuffs should be prohibited, and sleeves and collars should be kept buttoned to prevent hot metal slag or sparks from contacting the skin.

- Workers and persons responsible for worker health and safety should be informed that protective clothing may interfere with the body's heat dissipation, especially during hot weather or in hot industries or work situations (e.g., confined spaces).

Therefore, additional monitoring is required to prevent heat-related illness when protective clothing is worn under these conditions.

2. Eye and Face Protection

The employer should provide and require the use of welding helmets with the following eye and face protection: approved UV filter plates and safety spectacles with side shields or goggles for workers exposed to arc welding or cutting processes; goggles or similar eye protectors with filter lenses for oxyfuel gas welding, brazing, or cutting; and goggles or similar eye protectors with transparent lenses for resistance welding and brazing. Hand-held screens for shielding the face and eyes should not be used since they may inadvertently be held incorrectly. A report prepared by C.E. Moss [1985] provides a compendium of protective eyeware that may be helpful in choosing appropriate eye protection. All welding helmets must meet the requirements of 29 CFR 1910.252(e)(2)(ii), "Specifications for protectors." Eye and face protectors should be periodically inspected and maintained by the employer. Eye and face protectors should be sanitized before being used by another worker. In addition, submerged arc welders must, where the work permits, be enclosed in an individual bootn coated on the inside with a nonreflective material as set forth in 29 CFR 1910.252(e)(2)(ii).

3. Respiratory Protection

Engineering controls should be the primary method used to control exposure to airborne contaminants. Respiratory protection should be used by workers only in the following circumstances:

- During the development, installation, or testing of required engineering controls;
- When engineering controls are not feasible to control exposure to airborne contaminants during short-duration operations such as maintenance and repair; and
- During emergencies.

Respiratory protection is the least preferred method of controlling worker exposures and should not be used routinely to prevent or minimize exposures. When respirators are used, employers should institute a complete respiratory protection program that includes worker training at regular intervals in the use and limitations of respirators, routine air monitoring, and maintenance, inspection, cleaning, and evaluation of the respirator. Respirators should be used in accordance with the manufacturer's instructions. Each respirator user should be fit tested and, if possible, receive a quantitative, on-the-job evaluation of his or her respirator protection factor to confirm the protection factor assumed for that class of respirator. For additional information on the use of respiratory protection, refer to the NIOSH Guide to Industrial Respiratory Protection [NIOSH 1987a].

Selection of the appropriate respirator depends on the types of contaminants and their concentration in the worker's breathing zone. Before a respirator can be selected, an assessment of the work environment is typically necessary to determine the concentrations of specific metal fumes and other particulates, gases, or vapors that may be present. As an interim measure until the environmental assessment has been made, the evaluator should conduct an initial review of precautionary labels on filler metals, electrodes, and flux materials to make a best estimate of the appropriate class of respirators. Respirator types shall be selected in accordance with the most recent edition of the NIOSH Respirator Decision Logic [NIOSH 1987b]. The following respirators should be used if a carcinogen is present at any detectable concentration, or if any other conditions are present that are considered to be immediately dangerous to life or health (IDLH):

- A self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode.

- A combination respirator that includes a supplied-air respirator with a full facepiece operated in pressure-demand or positive-pressure mode and an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode.

When respirators must be selected for combinations of contaminants in different physical forms, combination cartridge and particulate filter air-purifying respirators may be acceptable under specific conditions as long as none of the agents are considered carcinogenic. The actual respirator selection should be made by a qualified individual, taking into account specific use conditions including the interaction of contaminants with the filter medium, space restrictions caused by the work location, and the use of welding helmets or other face and eye protective devices.

When welding is performed in confined spaces, the potential exists for a reduction in ambient oxygen concentrations. A self-contained breathing apparatus or supplied-air respirator with an auxiliary self-contained breathing apparatus must be used for oxygen concentrations below 19.5% (at sea level).

E. Labeling and Posting

In accordance with 29 CFR 1910.1200, "Hazard Communication," workers must be informed of exposure hazards, of potential adverse health effects, and of methods to protect themselves. Though all workers associated with welding processes should have received such information as part of their training, labels and signs serve as important reminders. Labels and signs also provide an initial warning to other workers who may not normally work near those processes. Depending on the process, warning signs may state a need to wear eye protection, hearing protectors, or a respirator; or they may be used to limit entry to an area without protective equipment. For transient nonproduction work, it may be necessary to display warning signs at the worksite to inform other workers of the potential hazards.

Labels on containers of filler metal, electrodes, and flux materials that are toxic shall include the following information: (1) the name of the metal and a warning describing its health hazards (for materials containing carcinogens, the warning should include a statement that fumes or gases from these materials may cause cancer), (2) instructions to avoid inhalation of or excessive skin or eye contact with the fumes of the materials, (3) instructions for emergency first aid in case of exposure, (4) appropriate instructions for the safe use of the materials, and (5) instructions for the type of personal protective clothing or equipment to be worn. Base metals that contain or are coated with materials containing carcinogens or other toxic metals (e.g., lead or mercury) should be clearly labeled or marked to indicate their contents before being welded. This same type of information must be posted in areas where welding is being performed.

All labels and warning signs should be printed in both English and the predominant language of non-English-reading workers. Workers who cannot read labels or posted signs should be identified so that they may receive information about hazardous areas and be informed of the instructions printed on labels and signs.

F. Sanitation

The preparation, storage, or consumption of food should not be permitted in areas where welding takes place. The employer should make handwashing facilities available and encourage the workers to use them before eating, smoking, using the toilet, or leaving the work site. Tools and protective clothing and equipment should be cleaned as needed to maintain a sanitary condition. Toxic wastes should be collected and disposed of in a manner that is not hazardous to workers or surrounding environments. No dry sweeping or blowing should be permitted in areas where welding is performed with materials containing carcinogens or other highly toxic metals. Vacuum pickup or wet mopping should be used to clean the work area at the end of each work shift or more frequently as needed to maintain good housekeeping practices. Collected wastes should be placed in sealed containers that are labeled as to their contents. Cleanup and disposal should be conducted in a manner that enables workers to avoid contact with the waste and to observe applicable Federal, State, or local regulations.

Uncovered tobacco products should not be permitted to be carried or used for smoking or chewing. Workers should be provided with and advised to use facilities for showering and changing clothes at the end of each work shift. Work areas should be kept free of flammable debris. Flammable work materials (rags, solvents, etc.) should be stored in approved safety cans.

G. Availability of Substitutes

Fume and gas composition may be affected by material substitution. Toxic agents in welding fumes and gases may require remedial action such as changing the electrodes, fluxes, or type of welding process if appropriate control measures cannot be implemented. Materials that may come into contact with welding processes (e.g., metals coated with oil and paint) should always be cleaned to prevent exposure to other toxic agents [DWI

1977]. Because impurities or contaminants are often contained in fluxes [Steel and Sanderson 1966] or base metal coatings [Pegues 1960], substitutions should be done cautiously to avoid introducing other toxic exposures. In practice, however, substitution is not always an alternative to minimizing exposures, since material and process selection usually depend on the type of weld required and the quality of the finished product.

APPENDIX

OSHA PELs, NIOSH RELs, and ACGIH TLVs for selected chemicals and physical agents associated with welding processes

Hazardous agent	OSHA PEL	NIOSH REL[a]	ACGIH TLV[b]
Acetylene	2,500 ppm (10% of lower explosive limit) (specific conditions: see 29 CFR 1915.12)	No exposure >2,500 ppm (2,662 mg/m^3), TWA	Gas acts as a simple asphyxiant without other significant physiologic effects. A TLV may not be recommended for each simple asphyxiant because the limiting factor is the available oxygen.
Aluminum	None	None	Aluminum as welding fume: 5 mg/m^3, 8-hr TWA
Arsenic, inorganic	10 µg/m^3, 8-hr TWA	2 µg/m^3, ceiling (15 min)[c] (carcinogen)	200 µg/m^3, 8-hr TWA
Beryllium	2 µg/m^3, 8-hr TWA; 5 µg/m^3, acceptable ceiling; 25 µg/m^3, maximum ceiling (30 min)	Not to exceed 0.5 µg/m^3[c] (carcinogen)	2 µg/m^3, A2
Cadmium	Fume: 0.1 mg/m^3, 8-hr TWA; 0.3 mg/m^3, ceiling Dust: 0.2 mg/m^3, 8-hr TWA; 0.6 mg/m^3, ceiling	Lowest feasible limit[c] (carcinogen)	Cadmium oxide fume as Cd, 0.05 mg/m^3, ceiling

(Continued)

See footnotes at end of table.

APPENDIX (Continued).--OSHA PELs, NIOSH RELs, and ACGIH TLVs for selected chemicals and physical agents associated with welding processes

Hazardous agent	OSHA PEL	NIOSH REL[a]	ACGIH TLV[b]
Carbon dioxide	5,000 ppm ($9,000\ mg/m^3$),[c] 8-hr TWA	10,000 ppm ($18,000\ mg/m^3$), TWA; 30,000 ppm ($54,000\ mg/m^3$), ceiling (10 min)[c]	5,000 ppm ($9,000\ mg/m^3$), 8-hr TWA[c]; 30,000 ppm ($54,000\ mg/m^3$), STEL
Carbon monoxide	50 ppm ($55\ mg/m^3$), 8-hr TWA;	35 ppm ($40\ mg/m^3$) TWA; 200 ppm ($229\ mg/m^3$), ceiling (no minimum time)[c]	50 ppm ($55\ mg/m^3$), 8-hr TWA; 400 ppm ($440\ mg/m^3$), STEL
Chromium(VI)	$100\ \mu g/m^3$, ceiling	Carcinogenic Cr(VI): $1\ \mu g/m^3$ TWA Other Cr(VI): $25\ \mu g/m^3$, TWA; $50\ \mu g/m^3$, ceiling (15 min)[c]	Water soluble: $50\ \mu g/m^3$, 8-hr TWA Certain water insoluble: $50\ \mu g/m^3$, 8-hr TWA, A1
Cobalt	$0.1\ mg/m^3$, 8-hr TWA[c]	NIOSH has concluded that there is insufficient evidence to warrant recommending a new PEL	Metal, dust, and fume $0.05\ mg/m^3$, 8-hr TWA
Copper fume	$0.1\ mg/m^3$, 8-hr TWA[c]	None	$0.2\ mg/m^3$, 8-hr TWA; dusts and mists as Cu, $1\ mg/m^3$
Fluorides, inorganic	$2.5\ mg/m^3$, 8-hr TWA	$2.5\ mg\ F/m^3$ TWA	$2.5\ mg/m^3$, 8-hr TWA

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See footnotes at end of table.

APPENDIX (Continued).--OSHA PELs, NIOSH RELs, and ACGIH TLVs for selected chemicals and physical agents associated with welding processes

Hazardous agent	OSHA PEL	NIOSH REL[a]	ACGIH TLV[b]
Hot environments	None	Sliding scale limits based on environmental and metabolic heat loads[c]	Sliding scale limits based on work-rest regimen and workload
Inert or nuisance dust	Total dust: 15 mg/m^3 Respirable dust: 5 mg/m^3 Note: these apply only to mineral dust	None	Nuisance particulates: total dust, 10 mg/m^3, 8-hr TWA; respirable dust, 5 mg/m^3, 8-hr TWA
Iron oxide fume	10 mg/m^3	None	5 mg/m^3, 8-hr TWA (welding fumes)[c]
Lead, inorganic	50 μg/m^3, 8-hr TWA; determine >8-hr exposure by formula (29 CFR 1910.1025)	<100 μg Pb/m^3, TWA; maintain air level so that worker blood lead remains ≤60 μg/100 g	150 μg/m^3
Magnesium oxide fume	15 mg/m^3, 8-hr TWA	None	10 mg/m^3, 8-hr TWA[c]

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See footnotes at end of table.

APPENDIX (Continued).--OSHA PELs, NIOSH RELs, and ACGIH TLVs for selected chemicals and physical agents associated with welding processes

Hazardous agent	OSHA PEL	NIOSH REL[a]	ACGIH TLV[b]
Manganese	5 mg/m^3, ceiling	None	Dust and compounds: 5 mg/m^3, 8-hr TWA Fume: 1 mg/m^3[c]
Molybdenum	5 mg/m^3 (soluble), 8-hr TWA; 15 mg/m^3 (insoluble), 8-hr TWA	None None	Soluble compounds: 5 mg/m^3, 8-hr TWA Insoluble compounds: 10 mg/m^3[c]
Nickel, inorganic and compounds	1 mg Ni/m^3, 8-hr TWA	0.015 mg Ni/m^3, TWA[c] (carcinogen)	Metal: 1 mg/m^3 Soluble compounds (as Ni): 0.1 mg/m^3, 8-hr TWA
Nitrogen oxides	NO_2: 5 ppm (9 mg/m^3), ceiling NO: 25 ppm (30 mg/m^3) 8-hr TWA	NO_2: 1 ppm (1.8 mg/m^3), 15 min ceiling NO: 25 ppm (30 mg/m^3), TWA[c]	NO_2: 3 ppm (6 mg/m^3), 8-hr TWA; 5 ppm (10 mg/m^3), STEL
Noise	90 dBA, 8-hr TWA	85 dBA, TWA; 115 dBA, ceiling[c]	85 dBA, 8-hr TWA; 115 dBA, ceiling
Ozone	0.1 ppm (0.2 mg/m^3), 8-hr TWA	None	0.1 ppm (0.2 mg/m^3), 8-hr TWA; 0.3 ppm (0.6 mg/m^3), STEL

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See footnotes at end of table.

APPENDIX (Continued).--OSHA PELs, NIOSH RELs, and ACGIH TLVs for selected chemicals and physical agents associated with welding processes

Hazardous agent	OSHA PEL	NIOSH REL[a]	ACGIH TLV[b]
Phosgene	0.1 ppm (0.4 mg/m^3), 8-hr TWA	0.1 ppm (0.4 mg/m^3), TWA; 0.2 ppm (0.8 mg/m^3), ceiling (15 min)[c]	0.1 ppm (0.4 mg/m^3), 8-hr TWA
Silica, crystalline	Respirable quartz: $\frac{250\ mppcf}{\%\ SIO_2+5}$ or $\frac{10\ mg/m^3}{\%\ SIO_2+2}$	Respirable free silica, 50 µg/m^3 TWA	Respirable dust for quartz and fused silica: 100 µg/m^3 Contained respirable quartz dust for tripoli: 100 µg/m^3 Respirable dust for cristobalite and tridymite: 50 µg/m^3
Silver	0.01 mg/m^3, 8-hr TWA[c]	None	Metal: 0.1 mg/m^3, 8-hr TWA Soluble compounds (as Ag): 0.01 mg/m^3, 8-hr TWA
Tin, inorganic compounds except oxides	2 mg/m^3, 8-hr TWA[c]	None	Metal: 2 mg/m^3, 8-hr TWA Oxide and inorganic compounds, except SnH_4 (as Sn): 2 mg/m^3, 8-hr TWA
Titanium dioxide	15 mg/m^3, 8-hr TWA	None	Nuisance particulate, 10 mg/m^3 of total dust

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See footnotes at end of table.

APPENDIX (Continued).--OSHA PELs, NIOSH RELs, and ACGIH TLVs for selected chemicals and physical agents associated with welding processes

Hazardous agent	OSHA PEL	NIOSH REL[a]	ACGIH TLV[b]
Tungsten and cemented tungsten carbide	None	Insoluble tungsten: 5 mg/m^3, TWA Soluble tungsten: 1 mg/m^3, TWA Dust of cemented tungsten carbide containing ≥2% cobalt: 0.1 mg Co/m^3, TWA Dust of cemented tungsten carbide containing >0.3% nickel: 15 g nickel/m^3, TWA[c]	Insoluble compounds: 5 mg/m^3, 8-hr TWA; 10 mg/m^3, STEL Soluble compounds: 1 mg/m^3, 8-hr TWA; 3 mg/m^3, STEL
Ultraviolet radiation	None	315-400 nm: 1.0 mW/cm^2 for periods >1,000 sec; total radiant energy shall not not exceed 1,000 mWsec/cm^2 (1.0 J/cm^2) for exposure times ≤1,000 sec 200-315 nm: see requirements in in NIOSH [1972a][c]	Prescribed time periods of allowable exposure based on measurements of effective irradiance
Vanadium	Vanadium pentoxide: dust, 0.5 mg/m^3 ceiling; fume, 0.1 mg/m^3, ceiling Ferrovanadium: 1 mg/m^3, 8-hr TWA	Vanadium compounds: 0.05 mg V/m^3, ceiling (15 min) Metallic vanadium and vanadium carbide: 1 mg V/m^3 TWA[c]	Respirable dust and fume: 0.05 mg/m^3, 8-hr TWA

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See footnotes at end of table.

APPENDIX (Continued).--OSHA PELs, NIOSH RELs, and ACGIH TLVs for selected chemicals and physical agents associated with welding processes

Hazardous agent	OSHA PEL	NIOSH REL[a]	ACGIH TLV[b]
Welding fumes	None	None	Total particulate that is not otherwise classified: 5 mg/m^3, 8-hr TWA
Zinc oxide	5 mg/m^3, 8-hr TWA	5 mg/m^3, TWA; 15 mg/m^3, ceiling (15 min)	Fume: 5 mg/m^3, TWA; 10 mg/m^3, STEL

[a]NIOSH TWA recommendations are based on time-weighted average (TWA) concentrations for up to a 10-hr workday and a 40-hr workweek over a working lifetime, unless otherwise noted.
[b]Definitions for ACGIH TLVs: A1--confirmed human carcinogen; A2--suspected human carcinogen; short term exposure limit (STEL)--a 15-min TWA exposure that should not be exceeded at any time during a workday even if the 8-hr TWA is within the TLV; ceiling--the concentration that should not be exceeded during any part of the workday.
[c]Denotes the lowest of the three exposure limits (OSHA PEL, NIOSH REL, or ACGIH TLV) listed for the given hazardous agent.

GLOSSARY

The definitions in this glossary were derived from the American Welding Society's Welding Terms and Definitions [AWS 1980], Welding Technology [Kennedy 1976], and Welding and Other Joining Processes [Lindberg and Braton 1976].

ARC CUTTING

Cutting processes that melt the metals to be cut with the heat of an arc between an electrode and the base metal.

ARC WELDING

Welding processes that produce coalescence of metals by heating them with an arc, with or without the application of pressure, and with or without the use of inert gases or filler metal.

CARBON ARC CUTTING

An arc cutting process in which metals are severed by melting them with the heat of an arc between a carbon electrode and the base metal.

CARBON ARC WELDING

An arc welding process that produces fusion of metals by heating them with an arc between a carbon electrode and the work. No shielding is used. Pressure and filler metal may or may not be used.

COLD WELDING

A solid-state welding process in which pressure is used at room temperature to produce coalescence of metals with substantial deformation at the weld.

ELECTRON BEAM WELDING

A welding process that produces coalescence of metals with the heat obtained from a concentrated beam composed primarily of high-velocity electrons impinging on the joint to be welded.

FLUX-CORED ARC WELDING

An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is provided by a flux contained within the tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

FURNACE BRAZING

A brazing process in which the parts to be joined are placed in a furnace heated to a suitable temperature.

GAS METAL ARC WELDING

An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture. Some variations of this process are called MIG or CO_2 welding (nonpreferred terms).

GAS TUNGSTEN ARC WELDING

An arc welding process that produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure and filler metal may or may not be used.

GOUGING

The forming of a bevel or groove by material removal.

LASER BEAM WELDING

A welding process that produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging on the members to be joined.

MIG WELDING

See preferred terms--**GAS METAL ARC WELDING** and **FLUX-CORED ARC WELDING**.

OXYACETYLENE WELDING

An oxyfuel gas welding process that produces coalescence of metals by heating them with a gas flame obtained from the combustion of acetylene with oxygen. The process may be used with or without the application of pressure and with or without the use of filler metal.

OXYFUEL GAS WELDING

Welding processes that produce coalescence by heating materials with an oxyfuel gas flame, with or without the application of pressure and with or without the use of filler metal.

PLASMA ARC CUTTING

An arc cutting process that severs metal by melting a localized area with a constricted arc and removing the molten material with a high-velocity jet of hot ionized gas issuing from the orifice.

PLASMA ARC WELDING

An arc welding process that produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the hot ionized gas issuing from the orifice, which may be supplemented by an auxiliary source of shielding gas. Shielding gas may be an inert gas or a mixture of gases. Pressure may or may not be used, and filler metal may or may not be supplied.

RESISTANCE WELDING

Welding processes that produce coalescence of metals with the application of pressure and with the heat obtained from resistance of the work to electric current in a circuit that includes the work.

SHIELDED METAL ARC WELDING

An arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used, and filler metal is obtained from the electrode.

SUBMERGED ARC WELDING

An arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc and molten metal are shielded by a blanket of granular fusible material on the work. Pressure is not used, and filler metal is obtained from the electrode or sometimes from a supplemental source (welding rod, flux, or metal granules).

TIG WELDING

See preferred term--**GAS TUNGSTEN ARC WELDING.**

TORCH BRAZING

A brazing process in which the heat required is furnished by a fuel gas flame.

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