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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.

ABSTRACT

This 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.

CONTENTS

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).

(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

(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.

(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).

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:

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

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.

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,

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.

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

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.

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.

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.

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.

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

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 List of Personal Hearing Protectors and Attenuation Data [NIOSH 1976]. Additional information on hearing protection devices may be found in the Compendium of Hearing Protection Devices [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

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,

- 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

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).

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.

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 (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 µg/m^3, ceiling	Carcinogenic Cr(VI): 1 µg/m^3 TWA	Water soluble: 50 µg/m^3, 8-hr TWA
		Other Cr(VI): 25 µg/m^3, TWA; 50 µg/m^3, ceiling (15 min)[c]	Certain water insoluble: 50 µg/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

(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]
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	Soluble compounds: 5 mg/m^3, 8-hr TWA
		None	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_2: 1 ppm (1.8 mg/m^3), 15 min ceiling	NO_2: 3 ppm (6 mg/m^3), 8-hr TWA; 5 ppm (10 mg/m^3), STEL
	NO: 25 ppm (30 mg/m^3) 8-hr TWA	NO: 25 ppm (30 mg/m^3), TWA[c]	
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

(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]
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

(Continued)

See footnotes at end of table.

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.

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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