NIOSH

Criteria for a Recommended Standard

Welding, Brazing, and Thermal Cutting

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

CRITERIA FOR A RECOMMENDED STANDARD

Welding, Brazing, and Thermal Cutting

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
DIVISION OF STANDARDS DEVELOPMENT AND TECHNOLOGY TRANSFER

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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 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

A	--Ampere
ACGIH	--American Conference of Governmental Industrial Hygienists
ANSI	--American National Standards Institute
API	--American Petroleum Institute
AWS	--American Welding Society
CDLSR	--California Division of Labor and Research
cfm	--cubic feet per minute
CI	--confidence interval
cm	--centimeter
CO	--carbon monoxide
CO_2	--carbon dioxide
db	--decibels
dBA	--decibel(s) measured on the A scale
DMSO	--dimethylsulfoxide
fpm	--feet per minute
ft	--foot
hr	--hour
in.	--inch
ILO	--International Labour Office
IR	--infrared
kW	--kilowatt
m	--meter
mg	--milligram
MHz	--megahertz
min	--minute
mm	--millimeters
MnO	--manganese oxide
mppcf	--millions of particles per cubic foot
NFPA	--National Fire Protection Association
NIOSH	--National Institute for Occupational Safety and Health
NO_2	--nitrogen dioxide
N_2O	--nitrous oxide
nm	--nanometer
OR	--odds ratio
OSHA	--Occupational Safety and Health Administration
PEL	--permissible exposure limit
PFT	--pulmonary function test
PMR	--proportional mortality ratio
ppm	--parts per million
REL	--recommended exposure limit
RF	--radiofrequency
SCE	--sister chromatid exchange
sec	--second
SiO_2	--silicon dioxide

SMR	--standard mortality ratio
SPF	--sun protection factor
TiO_2	--titanium dioxide
TLV®	--threshold limit value
TWA	--time-weighted average
UV	--ultraviolet

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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 VI and VII 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. Appendix A 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.

(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 (see explanation of terms in Chapter III).

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. Appendix B lists 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.

(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, 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 ultraviolet radiation (UV) 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 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 <u>Criteria for a Recommended Standard....Occupational Exposure to Hot Environments</u> [NIOSH 1986].

Section 10 - <u>Recordkeeping</u>

(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. INTRODUCTION

A. Scope

NIOSH has formalized a system for developing criteria on which to base standards for ensuring the health and safety of workers exposed to hazardous chemical and physical agents. The criteria and recommended standards are intended to enable management and labor to develop better engineering controls and more healthful work practices.

This document presents the criteria and recommended standards for preventing health impairment from exposures associated with welding. The criteria document was developed by the National Institute for Occupational Safety and Health (NIOSH) in response to Section 20(a)(3) of the Occupational Safety and Health Act of 1970. In this act, NIOSH is charged with the responsibility of developing criteria for toxic materials and harmful physical agents to describe exposure concentrations at which no worker will suffer impaired health or functional capacities or diminished life expectancy as a result of work experience.

This document contains information on workplace exposures that may occur during welding and the adverse health effects associated with these exposures (e.g., gastrointestinal disorders, cancer, and ocular, dermatological, reproductive, musculoskeletal, and chronic and acute respiratory diseases. For the purpose of this recommended standard, "welding" is defined as those processes that join or cut pieces of metal by heat, pressure, or both (e.g., arc welding, brazing, and cutting) [ILO 1972]. These processes differ only in the way heat is created and applied to the parts being joined and in the type of filler material used. Chapter III describes these processes.

Table II-1 lists specific welding processes and some of the potentially hazardous agents associated with them. This table should be used as a reference guide and not as a complete inventory of possible emissions. Chapter III contains more complete discussion of these agents. Laser and underwater welding processes are not included since they require specific control procedures that are beyond the scope of this document.

B. Number of Workers Potentially Exposed to Welding

The 1972-74 National Occupational Hazard Survey showed that an estimated 176,000 workers had a primary occupation of welder, brazer, or thermal cutter [Sundin 1972]. A follow-up survey in 1981-83 indicated that 185,000 workers were employed in these occupations [Sundin 1981]. These NIOSH surveys were limited to facilities that employed eight or more workers and did not account for any welding conducted at mining sites or government facilities.

Estimates indicate that the duties of more than 700,000 U.S. workers involve the welding of various types of materials within many different industries (e.g., manufacturing and construction) [Bureau of the Census 1984]. Census data from 1980 [Bureau of the Census 1984] indicated that 673,357 males and 39,242 females were employed as welders and cutters. Note that brazers were classified along with solderers in the census data and thus are not included in these employment figures.

C. Special Considerations for Controlling Welding Hazards

The hazards associated with welding can be divided into two categories: (1) the hazardous chemicals (e.g., fumes and gases) that are formed or released by the processes, and (2) the physical hazards such as ionizing and nonionizing radiation, noise, vibration, high temperatures, and electricity. Because of the many techniques applied in welding and the various types of materials used, it is often difficult to characterize exposures completely at any given time. However, as noted in Table II-1, specific gases and fumes are typically generated when certain welding processes are applied to known base metals. This knowledge can be used to implement good industrial hygiene practices before any comprehensive evaluation of the workplace is initiated.

This document discusses the adverse health effects that have been observed among workers who perform welding, but many of these effects cannot be attributed to any specific agent because of the possible additive or synergistic effects from mixed exposures. For example, welders have historically been exposed to asbestos as a result of using asbestos-containing materials or working in industries where asbestos was used as an insulation material. Many of the morbidity and mortality studies conducted on welders demonstrate an increased risk in respiratory diseases, including cancer. Because of the absence of exposure data for many of these studies, the etiology of the reported disease is unknown but often clinically resembles the diseases associated with workers exposed to asbestos. Although the potential for an asbestos exposure has decreased with the elimination of asbestos-containing materials used by welders, it still remains a possible concomitant exposure in some work environments (e.g., asbestos insulation around pipes).

Thus the recommendations developed from evaluating available data are intended to reduce exposures to chemical and physical agents by conformance with NIOSH RELs, OSHA PELs, or exposure limits set by other voluntary consensus groups (see Chapter I, Section 1, Definitions). To enable employers and workers to control exposures within the specified limits, criteria are provided for appropriate work practices, engineering controls, workplace monitoring, and personal protective equipment. Other recommendations include the establishment of comprehensive programs for medical surveillance and worker training.

Table II-1.--Specific welding processes and associated hazardous agents

Process	Hazardous agent
Brazing/cadmium filler	Cadmium
Flame cutting, welding	Carbon monoxide Nitric oxide (NO) Nitrogen dioxide (NO_2)
Gas metal arc welding (GMAW)/aluminum (Al) or aluminum-magnesium (Al-Mg)	Ultraviolet (UV) radiation Ozone
GMAW/stainless steel	Hexavalent chromium(VI) Nickel Ozone
GMAW, all types using carbon dioxide	Carbon monoxide
Gas tungsten arc welding/Al or Al-Mg	UV radiation
Shielded metal arc welding (SMAW), low-hydrogen electrodes	Fluorides UV radiation
SMAW/iron or steel	Iron oxide UV radiation
SMAW/stainless steel	Chromium(VI) Nickel UV radiation
Plasma cutting/aluminum	Noise Ozone

D. Existing Occupational Safety and Health Standards for Welding

The complexity and scope of welding processes have made them subject to many standards and regulations. The first welding standard was initiated in 1943, when the Division of Labor Standards of the U.S. Department of Labor, the International Acetylene Association, the National Electrical Manufacturers Association, and the American Welding Society (AWS) asked the American Standards Association (now the American National Standards Institute [ANSI]) to develop the American War Standard for Safety in Electric and Gas Welding and Cutting Operations. This American War Standard was published in 1944 as a guideline for health and safety during World War II, when large numbers of relatively inexperienced workers were employed as welders [AWS 1973a].

Under the Occupational Safety and Health Act of 1970, standards were promulgated covering welding, cutting, and brazing under Title 29 of the Code of Federal Regulations. The standards apply to workers in construction [29 CFR 1926.350-54], ship repairing [29 CFR 1915.31-36], shipbuilding [29 CFR 1916.31-36], longshoring [29 CFR 1917.31-36], and general industry [29 CFR 1910.251-54]. Most of the Federal standards were adopted from consensus standards developed by a variety of organizations, including the American Conference of Governmental Industrial Hygienists (ACGIH), AWS, ANSI, the National Fire Protection Association (NFPA), the Compressed Gas Association (CGA), the American Petroleum Institute (API), and the Rubber Manufacturers Association (RMA).

The Federal standards covering welding, cutting, and brazing are generally process- or design-oriented rather than performance- or exposure-limit-oriented. That is, though the standards refer to allowable limits of exposure, they actually prescribe work procedures or practices that are intended to minimize health and safety risks. Some of the potential hazards to which the standards are directed include fire, explosion, electric shock, UV radiation, infrared (IR) radiation, oxygen-deficient atmospheres, decomposition products of chlorinated solvents, fluorides, nitrogen dioxide, and toxic metals such as beryllium, cadmium, chromium, lead, mercury, and zinc [29 CFR 1910.1915-17, 1910.1926].

Environmental monitoring is prescribed to evaluate confined spaces for sufficient oxygen, to monitor exposures resulting from the heating of greased metals, and to check for the presence of flammable gases. Labeling is required on the packages holding fluoride-containing flux or filler metals to warn that ventilation is required to control the fumes and gases that may be produced. No sanitation procedures are specified. Some types of personal protective equipment are specified, including eye protectors, helmets, gloves, boots, aprons, and other clothing. Requirements for specific work practices are covered for a number of particularly hazardous operations, including working in confined spaces, handling compressed-gas cylinders, welding or cutting metal containers, and working on elevated surfaces. The engineering controls required are screens or booths to protect against UV radiation, and ventilation for enclosed areas and confined spaces. The general industry standards for welding, cutting, and brazing [29 CFR 1910.251-54] refer to the PELs as stated in 29 CFR 1910.1000. The construction standards for welding and cutting

[29 CFR 1926.350-54] incorporate by reference the ACGIH Threshold Limit Values (TLVs®). The maritime employment standards for welding, brazing, and thermal cutting [29 CFR 1915.31-36, 1916.31-36, 1917.31-36] do not specify or refer to environmental limits.

Since 1970, the ACGIH has recommended a TLV of 5 mg/m^3 for total particulates in welding fumes. In addition, the ACGIH recommends that specific constituents of the fumes and toxic gases also be considered in assessing airborne exposures from welding [ACGIH 1987-88]. For example, a TLV of 0.05 mg/m^3 (as Cr) is recommended for exposures to chromium(VI) by the ACGIH.

NIOSH has RELs for individual substances and physical agents found in the welding environment. These RELs are listed in Appendix A along with the current OSHA PELs and ACGIH TLVs.

E. NIOSH Recommendations That Differ From Current OSHA Regulations

Many of the exposure limits and program requirements recommended in this document are not currently required by OSHA, and other recommendations are intended to augment existing OSHA requirements. NIOSH recommendations that differ from current OSHA regulations include those that pertain to the following items:

- Adoption of NIOSH RELs (or in some instances, other limits proposed by voluntary consensus groups) for specific chemical and physical agents (see Chapter I, Section 1, Definitions).
- Initial and periodic medical surveillance.
- Labeling and posting for potential carcinogens.
- Warning of eye damage from looking at a welding arc.
- Warning of high noise areas.
- Criteria for heat stress.
- Recommendations for personal protective clothing and equipment, including the criteria for selecting appropriate types of respirators.
- Information to supplement the Hazard Communication Standard (29 CFR 1910.1200).
- Engineering controls and work practices.
- Requirements for food storage and consumption, use of tobacco products, use of cosmetics, and personal hygiene (availability of shower and locker facilities).
- Exposure monitoring, both initial and periodic.
- Recordkeeping.

III. CHARACTERISTICS OF WELDING PROCESSES

A. Identification of Processes

More than 80 different types of welding and allied processes are in commercial use, including brazing and thermal cutting (Figure III-1). The most commonly used processes are briefly discussed in this section. Definitions for types of welding processes appear in the Glossary. Appendix D lists industries that employ welders, brazers, and cutters, along with their respective standard industrial classification (SIC) codes.

1. Arc Welding

In arc welding, heat is created as electricity flows across a gap between the tip of the welding electrode and the metal. Arc welding is the most frequently used process. It encompasses numerous variations, depending on the types of electrodes, fluxes, shielding gases, and other equipment that may be used. The arc welding process involves the melting of an electrode by an electric current to form a molten puddle in the base metal. Because of the generated heat, the base metal also becomes molten at the joining surfaces, which bond upon cooling.

Electrodes are manufactured as bare wire or as wire lightly to heavily coated with flux material. Bare wire electrodes are the least expensive, but they are difficult to maintain, and they produce an inferior weld. Also, a coating of copper on filler materials may be used in place of a flux to prevent oxidation of the material before use. Flux material generally consists of asbestos, feldspar, fluorine compounds, mica, steatite (a form of talc), titanium dioxide, calcium carbonate, magnesium carbonate, or various aluminas. The flux prevents or removes oxides or other undesirable substances from the weld. Inert shielding gases such as helium, argon, or carbon dioxide are used in some variations of arc welding. These variations of arc welding are often referred to as shielded metal arc, metal inert gas, and plasma arc welding. The inert gas prevents oxygen and active chemicals in the atmosphere from reacting with the hot metal [AWS 1976].

2. Oxyfuel Gas Welding

Oxyfuel gas welding is the process by which heat from burning gases is used to melt the base metal without the use of welding rods; however, rods are used when extra metal is needed as a filler to obtain a complete bond. The composition of these consumable rods is very similar to that of the base metals. Some are coated with flux, the composition of which depends on the application.

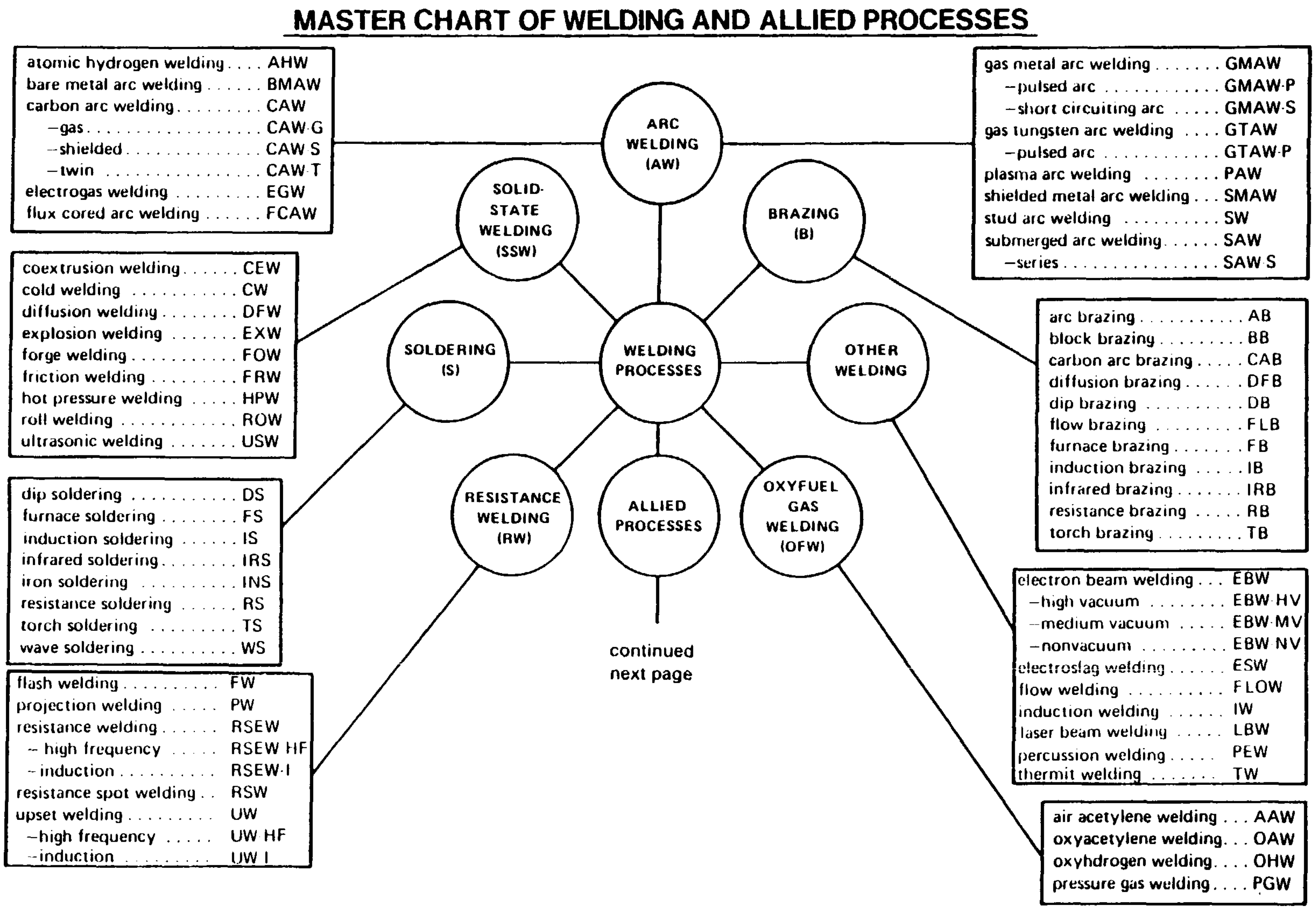

Figure III-1.--Welding and allied processes. (Copyright by the American Welding Society, 550 LeJeune Road, P.O. Box 351040, Miami, Florida 33135; reprinted with permission.)

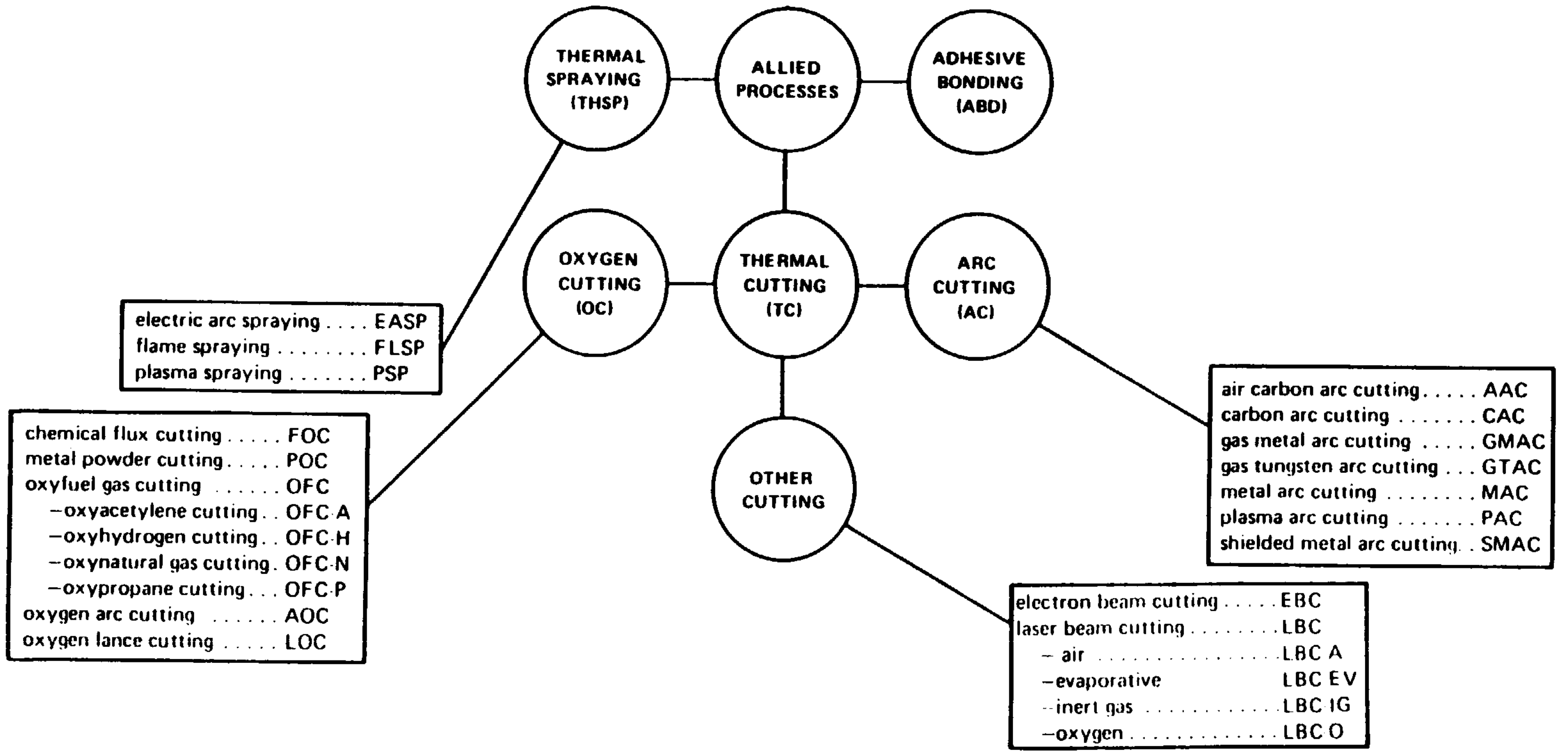

Figure III-1 (Continued).--Welding and allied processes. (Copyright by the American Welding Society, 550 LeJeune Road, P.O. Box 351040, Miami, Florida 33135; reprinted with permission.)

3. Resistance Welding

Resistance welding is a process in which pieces of metal are pressed together and an electric current is passed through them. At the contact point, there is sufficient resistance to cause an increase in temperature and melting of the metal.

4. Brazing

Brazing is the process by which metals are heated and joined together by a molten filler metal at temperatures exceeding 450°C (840°F) [AWS 1980]. Soldering, which is not included in this document, is similar to brazing, but it uses filler metals that have melting points below 450°C. The filler metal used in brazing may be in the form of wire, foil, filings, slugs, powder, paste, or tape. Fluxes must be used unless the process is performed in a vacuum, since oxidation of the brazed area will weaken the bond. The most common ingredients of fluxes are borates (e.g., lithium, potassium, and sodium), fused borax, fluoroborates (e.g., potassium and sodium), fluorides (e.g., lithium, potassium, and sodium), chlorides (e.g., lithium, potassium, and sodium), acids (e.g., boric acid and calcined boric acid), alkalis (e.g., potassium hydroxide and sodium hydroxide), and water (either as water of hydration or as an addition for paste fluxes) [AWS 1963].

5. Thermal Cutting

Thermal cutting includes processes that cut the metal by melting. These processes are divided into two main groups: oxygen and arc cutting. Oxygen cutting is performed on plain carbon, manganese, and low-chromium-content steels. When the metal is heated and exposed to oxygen, it oxidizes and melts. Flame cutting uses a fuel gas (or a combination of gases) such as acetylene, hydrogen, natural gas, or propane that burns and produces sufficient heat to vaporize and separate the metal. Arc cutting is used with nonferrous metals, stainless steels, or steels with a high chromium or tungsten content [AWS 1980].

B. Potential for Exposure

Welding, brazing, and thermal cutting processes generate exposures to many chemical and physical agents. Chemical and physical agents produced by these processes are described in the following sections, which identify the source, mechanism of production, disposition, and exposure concentrations found in many occupational environments. The potential exists for other confounding exposures (e.g., asbestos and heat) in the work environment of welders and needs to be assessed for each welding process.

1. Fumes and Other Particulates

A fume is generated by volatilization of melted substances with subsequent condensation of solid particles from the gaseous state [Dinman 1978]. For the processes discussed in this document, temperatures may range from about 450°C (840°F) for brazing [AWS 1980] to well above 15,000°C (27,000°F) for plasma arc cutting [Grimm and

Kusnetz 1962; Siekierzynska and Paluch 1972]. The single largest source of fumes is the filler metal being used [Jones 1967; Heile and Hill 1975].

Fumes may also originate from the base metal [Jones 1967], from coatings applied to the base metal [Pegues 1960; Oliver and Molyneux 1975], and from the flux or electrode coating [Thrysin et al. 1952]. Fume particles typically have a diameter of less than 1 micrometer (μm) [Hewitt and Hicks 1973; Heile and Hill 1975; Akselsson et al. 1976].

Fumes are not the only sources of airborne particulates. Fluxes and filler metals used in powdered form (e.g., in submerged arc welding and furnace brazing) may enter the air as fugitive dusts. Mineral and metal dusts may also be produced when material is pulverized during the cleaning of welds and brazes by surface brushing or grinding [Moreton et al. 1975]. Historically, the potential has also existed for asbestos exposure during welding processes. These exposures often occurred as a result of using materials that contained asbestos, disturbing asbestos insulation while welding, or working near other operations that used asbestos.

Steel and Sanderson [1966] investigated the composition of welding fumes to determine the extent of impurities that may be present in fluxes. Flux that is formulated into a coating for stick electrodes may generate shielding gas, produce slag, alloy with rods, or act as binders. In one of their experiments, these investigators conducted shielded metal arc welding on mild steel in a test chamber using 12 different commercial electrodes. Air samples were collected at a distance from the source of exposure that corresponded to the breathing zone of a welder standing upright. On several occasions, fume concentrations exceeded NIOSH RELs for lead and vanadium pentoxide. Chromium(VI), copper, and manganese were also detected.

The chemical composition of the airborne fumes generally reflects the elemental composition of the base and filler metals and the flux, but the fume components may have different chemical forms. Thus concentrations of the various fume components may vary for each job and process and are best determined on a case-by-case basis.

a. Alkali Metals and Alkaline Earths

The airborne concentrations of calcium, magnesium, potassium, and sodium are significantly greater in the emissions from lime (low-hydrogen) electrodes than in those from nonlime electrodes [Morita and Tanigaki 1977; Kimura et al. 1974]. Although concentrations vary greatly within the two classes, low-hydrogen electrodes generally produce higher concentrations of calcium, magnesium, potassium, and sodium in their fumes.

b. Aluminum

Aluminum is generally found in small quantities in the fumes from all types of electrodes, both low-hydrogen and non-low-hydrogen.

Morita and Tanigaki [1977] reported a range of 0.21% to 1.44% aluminum (as Al_2O_3), and Kimura et al. [1974] noted a range of 0.1% to 0.8% in the fumes for all electrodes tested.

c. **Beryllium**

Bobrishchev-Pushkin [1972] evaluated the composition of fumes produced by the electron beam welding of beryllium bronze. The welding was done in a vacuum chamber that was flushed with air before opening. The purged air was filtered, and the collected fumes were analyzed for beryllium. As in most electron beam welding, two pieces of base metal (2% beryllium content) were joined without the use of a filler metal. Samples of the purged air contained detectable amounts of beryllium in only 5 of the 44 samples. However, periodic cleaning by dry scrubbing of the vacuum chamber walls caused redispersion of fumes that contained beryllium concentrations of 130 to 150 $\mu g/m^3$ in the chamber and 4 $\mu g/m^3$ in the breathing zones of welders working outside the chamber.

d. **Cadmium**

Cadmium concentrations in the breathing zone have been reported to be 10 to 250 $\mu g/m^3$ during shipboard brazing with a silver- and cadmium-based filler metal [Oliver and Molyneux 1974]. Cadmium-bearing alloys are used in more than 50% of all brazed joints [Timmins et al. 1977].

e. **Chromium**

Both the chromium concentration and its oxidative state vary within the fumes depending on the welding or cutting process and the base metal. Virtamo [1975] compared fume composition in shielded metal arc welding, gas tungsten arc welding, gas metal arc welding, and plasma arc cutting. These operations were performed on high-alloy, nickel-chromium stainless steel to determine the relative amounts of nickel, chromium(VI), and total chromium evolved in the fumes. Analysis of breathing zone samples indicated the following:

- Shielded metal arc welding produced the highest water-soluble chromium(VI) fume concentrations--as high as 720 $\mu g/m^3$.

- Gas tungsten arc welding produced chromium(VI) concentrations below the 10-$\mu g/m^3$ detection limit in 8 of 10 samples (the highest concentration found was 45 $\mu g/m^3$).

- No chromium(VI) was detected during plasma arc cutting or gas metal arc welding.

While surveying Swedish worksites, Ulfvarson [1981b] found higher chromium concentrations with shielded metal arc welding than with gas metal arc welding on stainless steel. The median breathing zone concentration of chromium [almost all soluble chromium(VI)] was

150 $\mu g/m^3$ at 86 worksites where shielded metal arc welding was performed. For gas metal arc welding, the median breathing zone concentration of chromium (mostly insoluble) was about 20 $\mu g/m^3$ at 41 worksites.

At a large maintenance shop, Arnold [1983] assessed the exposures of three groups of welders. The first group performed gas tungsten arc and gas metal arc welding. Their breathing zone samples all contained <6 $\mu g/m^3$ of chromium(VI). Group II performed shielded metal arc welding and had breathing zone concentrations of chromium(VI) that averaged 14 $\mu g/m^3$, with a high of 90 $\mu g/m^3$. Group III used a variety of welding methods--mostly shielded metal arc welding (including flux cored arc and gas metal arc welding). Within this group, the average chromium(VI) concentration was 64 $\mu g/m^3$, with a high of 329 $\mu g/m^3$.

Both Lautner et al. [1978] and Ulfvarson [1981b] found that shielded metal arc welding produced the highest percentage of chromium(VI) in the fumes. When electron spectroscopy was used for chemical analysis (ESCA), gas metal arc and gas tungsten arc welding of stainless steel produced only traces of chromium(VI) (concentrations too small to be quantified). Shielded metal arc welding generated 73% of the total chromium in the fumes as chromium(VI) (mean net mass = 1,016 μg chromium(VI)/filter).

f. Fluorides

The inclusion of fluorspar in low-hydrogen (lime) electrodes produces significant amounts of fluoride compounds in welding fumes. In a study conducted by Kimura et al. [1974], welding fumes contained 11% to 18% fluoride. Another study [Persinger et al. 1973] reports that the fumes contained 14% to 23% fluoride when low-hydrogen electrodes were used for shielded metal arc welding on mild and high-tensile steel. Tebbens and Drinker [1941] found that high-alloy electrodes containing 1 to 5 mg fluoride per electrode generated fumes that contained 9% to 26% fluoride compounds. This high percentage was partly due to the low melting points of the fluoride compounds. Only negligible amounts of hydrogen fluoride were detected in the welding emissions.

g. Iron

Iron is the main constituent of the fume when welding is performed on non-alloy steel. Dreesen et al. [1947] studied arc welders in steel ship construction and reported welding fumes with iron concentrations above 20 mg/m^3. Ulfvarson [1981b] collected breathing zone samples for welders performing shielded metal arc and gas metal arc welding. The geometric mean concentration for iron was 14 mg/m^3 during the welding of unpainted non-alloy steel and 30 mg/m^3 during the welding of painted non-alloy steel. Akbarkhanzadeh [1979] surveyed British worksites (mostly shipyards) where shielded metal arc welding was being performed on mild steel. The mean concentration of iron (ferric oxide) from 209 breathing zone samples was 2 mg/m^3. The iron concentration increased linearly with increasing arc current (correlation coefficient = 0.323, $p<0.001$). Kleinfeld et al. [1969] sampled welders while they performed oxyfuel cutting and shielded metal arc welding; they found concentrations of iron oxide ranging from 0.65 to 1.7 mg/m^3 inside the welders' face shields and from 1.6 to 12 mg/m^3 outside the face shield.

h. Lead

Because zinc may contain lead as an impurity, significant amounts of lead can be generated when welding zinc-primed steel or steel that has been hot-dipped in zinc. Pegues [1960] determined lead concentrations from air samples collected in the breathing zone of workers performing oxyacetylene cutting and arc welding on zinc-coated steel. Welding was performed in a confined space without ventilation on steel that was protected by hot-dip galvanization and on steel that was painted with zinc silicate. During arc welding, breathing zone concentrations of lead ranged from 0.9 to 15.2 mg/m^3 with the zinc-silicate-coated steel, and from 0.4 to 0.7 mg/m^3 with the galvanized steel. During oxyacetylene welding, lead concentrations ranged from 1.2 to 3.5 mg/m^3 with the zinc-silicate-coated steel, and from 0.2 to 0.7 mg/m^3 with the galvanized steel.

i. Manganese

Akbarkhanzadeh [1979] collected breathing zone samples from welders performing shielded metal arc welding of mild steel coated with an unspecified primer and found average manganese fume concentrations of 0.14 mg/m^3. By comparison, breathing zone samples from welders performing shielded metal arc and gas metal arc welding had average manganese concentrations of 3.1 mg/m^3 during welding on primed mild steel and 1.4 mg/m^3 during welding on unprimed mild steel [Ulfvarson 1981].

The percentage of manganese in welding fumes was reported to be relatively independent of the type of electrode [Kimura et al. 1974; Morita and Tanigaki 1977]. In a study of 61 brands of electrodes of different composition [Morita and Tanigaki 1977], the level of manganese oxide (MnO) in the fume ranged from 2.5% to 9.5%. In a similar study of 25 brands of electrodes, Kimura et al. [1974] observed fumes containing 3.3% to 11.2% manganese as MnO. Fumes from ilmenite electrodes tended to have higher concentrations of manganese compared with those generated from lime electrodes.

j. Nickel

Virtamo [1975] assessed the nickel content of fumes generated from shielded metal arc welding, gas metal arc welding, and plasma arc cutting of stainless steel. Shielded metal arc welding produced nickel concentrations that ranged from trace amounts to 160 μg/m^3; gas metal arc welding produced concentrations as high as 60 $\mu g/m^3$; and plasma arc cutting produced concentrations up to 470 $\mu g/m^3$. When Ulfvarson et al. [1981] surveyed welders who were performing shielded metal arc and gas metal arc welding of stainless steel, a median breathing zone concentration of approximately 25 μg nickel/m^3 was determined for shielded metal arc and approximately 5 μg nickel/m^3 for gas metal arc welding. Bernacki et al. [1978] reported an average airborne concentration of 6 μg nickel/m^3 (with a high of 46 μg nickel/m^3) from welding nickel-alloyed steel. Wilson et al. [1981] examined various maintenance welding operations at a chemical plant and found that the highest nickel concentrations were produced when welding was conducted on stainless steel inside distillation towers. Airborne concentrations of nickel from 22 of 23 samples exceeded the NIOSH REL of 15 $\mu g/m^3$. The mean concentration of nickel was 3.65 $\mu g/m^3$, with a high of 17.6 $\mu g/m^3$.

k. Silica

Silica in welding fumes originates from the coating on the electrode, which varies in quantity depending on the type of electrode used. Twenty-six brands of ilmenite and lime titania electrodes produced fumes containing 18% to 22% silicon as silicon dioxide (SiO_2); two brands of iron powder/iron oxide electrodes produced fumes containing 8% and 12% SiO_2; and 10 brands of lime electrodes produced fumes containing 4% to 11% SiO_2 [Kimura et al. 1974].

In a study of 61 brands of electrodes, Morita and Tanigaki [1977] observed that the mean silica contents of fumes were as follows: (1) 33% for 7 high-titania and iron powder/iron oxide electrodes, (2) 22% for 26 brands of ilmenite and lime titania electrodes, (3) 12% for 1 high-cellulose electrode produced, and (4) 6% for 27 low-hydrogen electrodes.

Tebbens and Drinker [1941] observed the presence of silica in fumes generated from the shielded metal arc welding of mild steel. Silica and silicates are commonly used ingredients in fluxes on mild-steel-covered electrodes. When two such electrodes were tested, one generated fumes containing 15% crystalline silica plus a high silicate content; fumes from the other contained no crystalline silica but were high in silicates. The two electrodes generated comparable amounts of silicon (18% to 22% of the total fume), which was present as soluble silicates or amorphous silica. X-ray diffraction was used to confirm the absence of crystalline silica.

l. Titanium

In two studies [Morita and Tanigaki 1977], ilmenite, lime titania, and high-titania electrodes generated similar percentages of titanium in fumes. In the first study, 30 of these types of electrodes produced a range of 0.6% to 2.3% titanium as titanium dioxide (TiO_2). When 30 different brands of iron oxide/iron powder and low-hydrogen electrodes were tested in that same study, a range of 0.1% to 0.4% TiO_2 was found in the fume. The second study [Kimura et al. 1974] examined 25 brands of electrodes. Thirteen brands of ilmenite, lime titania, and titania electrodes produced a range of 0.6% to 5.5% TiO_2 in the fume; the remaining 12 iron powder/iron oxide and lime electrodes generated fumes containing 0.2% to 0.9% TiO_2.

m. Zinc

In a study of oxypropane flame cutting and shielded metal arc welding in a shipyard [Bell 1976], fumes containing zinc were generated from the protective coating on the metal. Breathing zone concentrations ranged from no detectable zinc to 8.6 mg/m^3. Shielded metal arc welding of metal plate treated with zinc powder and zinc chromate primers produced fumes containing up to 74 mg $zinc/m^3$ when ventilation was poor. A report on fumes from welding and flame cutting processes in the shipbuilding and ship-repairing industry [IIW 1970] showed breathing zone zinc concentrations as high as 44 mg/m^3. Ulfvarson [1981b] collected breathing zone samples from welders who were gas metal arc welding on mild steel that was either untreated or coated with a zinc tetraoxychromate/iron oxide primer. Samples collected during the welding of untreated steel had a mean zinc concentration of 0.11 mg/m^3, and those collected during the welding of primer-coated steel had a mean zinc concentration of 0.43 mg/m^3. Dreesen et al. [1947] reported zinc concentrations in area samples that exceeded 12 mg/m^3 (15 mg/m^3 expressed as zinc oxide) in welding fumes produced from arc welding on steel during ship repair. Pegues [1960] (see subsection 1,h, Lead, of this chapter) analyzed fume samples collected from workers performing oxyacetylene cutting and arc welding on zinc-coated steel in a confined space without ventilation. Steel that had two types of zinc-coatings (e.g., zinc silicate and galvanized steel) were evaluated to determine the generation of zinc in the fumes. The zinc-silicate-coated steel produced a mean zinc concentration of 19.81 mg/m^3 during electric arc welding and 12.28 mg/m^3 during oxyacetylene cutting. Electric arc welding of galvanized steel produced a mean zinc concentration of 6.63 mg/m^3. No exposures to zinc were detected during oxyacetylene cutting.

2. Specific Gases

A number of toxic gases such as carbon monoxide, oxides of nitrogen, ozone, and various photochemical and pyrolytic decomposition products of halogenated hydrocarbons are present or produced by chemical reactions during welding. Fuel gases that may be released (such as propane, acetylene, and hydrogen) are asphyxiants. These gases and oxygen may combust during use [Occupational Health (London) 1975]. The lower explosive limits (LELs) for some of these gases are quite low--for example, 2.3% for propane, 4.1% for hydrogen, and 2.5% for acetylene. Oxygen is hazardous at higher than normal concentrations because it increases the flammability of materials (e.g., clothes) [Jefferson 1970].

Shielding gases such as argon, nitrogen, helium, and carbon dioxide (CO_2) may also be present. Alone, these gases do not normally pose a hazard; however, in confined spaces they may displace the oxygen-containing air and give no warning of oxygen deficiency because they are odorless and colorless.

Many of the gases that may be encountered during various welding processes are listed below with information on their source of generation and reported concentrations.

a. Carbon Monoxide

Carbon monoxide CO exposures often result from the reduction of CO_2 used for shielding in gas metal arc welding. de Kretser et al. [1964] found CO concentrations often approaching 300 ppm when CO_2 exposures were measured at 1400 parts per million (ppm) during gas metal arc welding. Ulfvarson [1981b] found CO exposures to be sporadic and at low concentrations in many Swedish work sites except where gas metal arc welding was being done. At the latter sites, about 10% of the measurements had CO readings above 50 ppm, with peak readings of 150 ppm. Press and Florian [1983] found that for gas metal arc welding, CO concentrations increased as the percentage of carbon dioxide was increased in the shielding gas.

Erman et al. [1968] measured CO concentrations in poorly ventilated confined spaces during shipbuilding operations. Welding was done on steel with CO_2 gas metal arc welding. CO concentrations increased as the duration of welding increased. In a space of 4.9 m^3, CO concentrations exceeded 160 mg/m^3 (145 ppm) within 40 min. Ulfvarson et al. [1981a] assessed the generation of CO during flame cutting of primed steel. They found that in a laboratory setting, CO concentrations up to 35 ppm were generated when the ventilation was poor. Flame cutting of primed steel during ship repair and construction in confined spaces produced CO concentrations exceeding 100 ppm.

b. Oxides of Nitrogen

An arc or a very high-temperature flame may cause the oxygen and nitrogen in the air to combine and form oxides of nitrogen. One combustion product, nitrogen dioxide (NO_2), has been detected in shielded arc welding, oxyacetylene welding, arc gouging [Fay et al. 1957], gas metal arc welding [Erman et al. 1968], submerged arc welding, and oxyacetylene and oxypropane cutting [IIW 1970].

Tests performed with tungsten electrodes produced 0.3 to 0.5 ppm of nitrogen oxides with helium shielding and 2.5 to 3.0 ppm with argon shielding. The higher concentrations for both were obtained when the shield gas flow rate was doubled.

Ferry and Ginther [1953] found lower NO_2 concentrations for oxyacetylene welding, argon-shielded gas metal arc welding, and carbon arc gouging. The authors speculated that the increase in current for gas metal arc welding produced the higher NO_2 concentrations. Akbarkhanzadeh [1979], however, found no relationship between the current and the generation rates for nitrogen oxides when shielded metal arc welding was performed on mild steel. Ferry and Ginther [1953] observed that nitrogen dioxide concentrations were always greatest in the area of visible fume (within 0.15 m of the arc). At greater distances from the arc, the concentrations decreased in all directions except in the direction of the fume stream. The authors suggested that NO_2 is formed thermally and diffuses away from the arc. In a study [IIW 1980] that used oxyacetylene welding, flame size was an important factor in the generation of nitrogen oxides. Generation rates for nitrogen oxides were 10 times higher with an unrestricted flame length than with a 10-mm flame. In addition, increasing blowpipe size from 1 to 8 produced dramatic increases in nitrogen oxide concentrations. Ventilation that is adequate to control exposures to total fumes is sufficient to control nitrogen oxide exposures [Ferry and Ginther 1953; Akbarkhanzadeh 1979; IIW 1980].

Octavian and Nicolae [1968] observed that nitrogen oxides are formed at a distance from plasma arc cutting or argon-shielded arc welding, with maximum formation rates at 1.75 to 2.5 m and 4 m, respectively. Nitrogen oxide concentrations were determined by drawing air through a quartz tube at various distances from the welding operations and therefore measuring only those oxides formed by UV radiation.

Press [1976] found that for plasma arc cutting of aluminum alloys with an argon/hydrogen mixture, the highest measured concentrations were 2 ppm for NO_2 and 9 ppm for nitrous oxide (N_2O). Both concentrations were determined in the absence of ventilation. Siekierzynska and Paluch [1972] examined emission rates of nitrogen oxides for plasma arc cutting on various base metals that were 0.5 mm thick. Although N_2O concentrations were not given, generation rates were reported to be very similar for cutting mild steel (150 mg/sec), alloy steel (140 mg/sec), copper (70 mg/sec), brass (80 mg/sec), and aluminum (70 mg/sec). The NO_2 emission rates were 50 mg/sec for mild steel, 40 mg/sec for alloy steel, 45 mg/sec for copper, 50 mg/sec for brass, and 40 mg/sec for aluminum. Concentrations as high as 100 ppm have been reported [Maddock 1970; Mangold and Beckett 1971].

c. Ozone

In the presence of UV light, atmospheric oxygen can convert to ozone [Lunau 1967]. Among the various welding processes, gas metal arc and gas tungsten arc welding produce the highest ozone concentrations, especially when aluminum is used as a base metal [Lunau 1967; Press and Florian 1983; Ditschun and Sahoo 1983].

In studies of argon-shielded arc welding of aluminum, Lunau [1967] found that after 3 to 5 min with a 200-ampere (A) current density, ozone concentrations averaged 5.1 ppm; with a 250-A current density, ozone was 7.5 ppm; and with a 300-A current, ozone was 8.4 ppm. All concentrations decreased over time because of strong thermal upcurrents formed from the heat during welding. Shironin and Dorosheva [1976] also found an increase in ozone concentrations with increasing current density. With continuous argon-shielded arc welding, breathing zone samples collected from welders indicated an average ozone concentration of 0.6 mg/m^3 when an 80-A current density was used. This concentration increased to 1.0 mg/m^3 at a 300-A current density; with pulsed arcing, the concentrations were 0.5 mg/m^3 for a 50% duty cycle and 0.7 mg/m^3 for a 75% duty cycle. When Ditschun and Sahoo [1983] assessed the generation of ozone during gas metal arc welding of copper-nickel and nickel-aluminum bronze alloys, ozone concentrations varied from 0.07 to 0.19 ppm.

Ferry and Ginther [1953] found that when argon-shielded gas tungsten arc welding was performed on a copper block, the breathing zone concentration of ozone was 0.1 ppm with a 55-A current and 0.5 to 0.6 ppm with a 110-A current. When a helium shield was used, the ozone concentration was 0.1 ppm with either current level.

The spatial distribution of ozone concentrations has been studied under various conditions [Fay et al. 1957; Frant 1963; Lunau 1967]. Ozone generation diminished as the distance from the arc increased [Lunau 1967]. In argon-shielded gas tungsten arc welding of aluminum, ozone concentrations were consistently higher than with argon-shielded gas metal arc welding. The author postulated that the high-energy (short-wavelength) UV rays resulting from gas tungsten arc welding caused more ozone formation.

Fay et al. [1957] also found that ozone concentrations were higher at 0.15 m from the arc in argon-shielded gas metal arc welding than at 0.60 m. However, the opposite was observed with argon-shielded gas tungsten arc welding, regardless of the metal welded or the current used. Frant [1963] also studied ozone concentrations in argon-shielded gas tungsten arc welding but found that the rate of ozone formation measured in a quartz tube was 10 times higher at 0.2 m than at 0.5 m from the arc.

Ferry and Ginther [1953] found that the shielding gas had a decided effect on ozone formation. Changing from argon to helium in gas tungsten arc welding caused ozone concentrations in the breathing zone to decrease from 0.5-0.6 ppm to 0.1 ppm regardless of the current level. Frant [1963] observed a similar reduction when using a CO_2 shield. In gas metal arc welding of steel, argon shielding produced 33 μg ozone/min, and carbon dioxide shielding produced 7 μg ozone/min when measured in a quartz tube placed 30 cm from the arc.

Several authors have shown that the type of base metal can affect the rate of ozone production. Frant [1963] found that ozone was produced at a concentration of 300 μg/min during argon-shielded gas metal arc welding on aluminum, compared with only 33 μg/min during argon-shielded gas metal arc welding on steel. Lunau [1967] showed large variations in ozone concentrations depending on the particular aluminum alloy being welded. Argon-shielded gas metal arc welding on pure aluminum produced 6.1 ppm ozone at 0.15 m from the arc; welding under the same conditions on a 5% magnesium alloy of aluminum produced only 2.3 ppm ozone; and welding on a 5% silicon alloy of aluminum produced 14.5 ppm ozone. Press and Florian [1983] observed that shielded metal arc welding of aluminum produced ozone concentrations 10 times higher than shielded metal arc welding of mild steel. In addition, much higher ozone concentrations occurred when a silicon alloy electrode was used for welding aluminum than when a magnesium alloy electrode was used.

d. Decomposition Products of Organics

Trichloroethylene and tetrachloroethylene are solvents commonly used to degrease metals. They may therefore be present on the surface of recently cleaned metal parts or in the atmosphere where welding processes are being performed. Ultraviolet radiation may react with the vapors of those solvents and produce a number of irritating and toxic gases as a result of photooxidation. Trichloroethylene may decompose into dichloroacetyl chloride, phosgene, hydrogen chloride, and chlorine [Rinzema 1971]. Tetrachloroethylene may yield trichloroacetyl chloride, phosgene [Andersson et al. 1975], hydrogen chloride, and chlorine [Rinzema 1971]. Methyl chloroform (1,1,1-trichloroethane) appears to undergo relatively little decomposition in the welding environment [Rinzema 1971].

Dahlberg and Myrin [1971] assessed 10 welding workshops and found that roughly five times as much dichloroacetyl chloride as phosgene was formed where welding was done in the presence of trichloroethylene vapor. There was almost a complete conversion of trichloroethylene vapor to phosgene (1.5 ppm) and dichloroacetyl chloride (10 ppm) at 30 cm from an argon-shielded aluminum welding arc located 4 m from a degreaser. In other workshop environments, Dahlberg and Myrin [1971] found 0.01 to 0.3 ppm of phosgene and 0.03 to 13 ppm of dichloroacetyl chloride.

Andersson et al. [1975] studied the formation of trichloroacetyl chloride and phosgene from tetrachloroethylene vapor during shielded metal arc and gas metal arc welding. These two hazardous products were formed in equal proportions. The authors recommended that welding be avoided in work environments contaminated with tetrachloroethylene.

A variety of other potentially toxic gases may be produced when the welding process inadvertently heats certain other materials. For instance, residual oil on steel may emit acrolein during welding [de Kretser et al. 1964].

3. Physical Agents

The potential exists for exposure to a variety of physical agents during the welding process. Workers may be subjected to excessive heat in the welding environment [NIOSH 1986], radiation emitted from the welding processes (including ionizing radiation and nonionizing radiation in the IR, visible, and UV ranges [Fannick and Corn 1969], noise, and electricity. The following types of exposures are representative of those that have been specifically documented in the work environments of welders.

a. Electromagnetic Radiation

Optical radiation may be produced by electric or plasma arcs. Radiation from a 50-A arc ranges from a wavelength of 200 to 800 nm [Marshall et al. 1977]. Levels produced from oxyfuel welding, torch brazing, and oxygen cutting are lower than levels produced by other welding methods [Moss and Murray 1979].

Sliney et al. [1981] conducted a study to determine the effectiveness of transparent welding curtains that were designed to block exposure to "blue light." The transparent curtains were most effective in blocking the wavelengths between 400 and 500 nm. These wavelengths are known to cause photochemical injury to the retina. The energy emitted from shielded metal arc welding was determined by van Someren and Rollason [1948] using a 4-gauge covered electrode operating at a 280-A current. The relative spectral distribution of emitted optical radiation was 5% in the UV range, 26% in the visible range, and 69% in the IR range.

Various factors can affect the radiation intensity from welding and cutting arcs [Dahlberg 1971; Lyon et al. 1976; Bartley et al. 1979; Bennett and Harlan 1980]. Increasing current flow causes a sharp increase in UV emissions. Gas metal arc welding of aluminum produces much greater UV intensity than gas tungsten arc welding. UV emissions increase by a factor of 10 when using magnesium instead of aluminum as an alloying material. The use of argon gas for shielding significantly increases the intensity of the optical radiation compared with carbon dioxide or helium as a shielding gas. As the amount of fume increases, the amount of radiation is reduced proportionately. When gas tungsten arc welding is performed on aluminum-magnesium alloys, the amount of UV emitted decreases as the arc length increases.

Tip size, flame type, and filler metal composition are other variables that affect the amount of UV, visible, and IR radiation produced by oxyfuel welding [Moss and Murray 1979]. Marshall et al. [1980] assessed the amount of optical radiation that was generated from carbon arc cutting. The results of those tests demonstrated that other physical agents such as sparks and noise present more serious hazards than optical radiation. The authors stated that the observed low level of optical radiation produced was probably due to the removal of particulate material from the air, which left no material to become luminescent.

IR radiation can be absorbed by a worker's clothing and skin [Moss et al. 1985] and can elevate the skin temperature and contribute to the body's heat load. Light-colored, loose clothing reduces the heating of the skin.

b. Electricity

Electrical shock from arc and resistance welding is a common hazard and can be sufficient to paralyze the respiratory system or to cause ventricular fibrillation and death. This risk is highest when equipment is in disrepair (e.g., worn insulation) or when electrical resistance through the welder is decreased (e.g., by sweat or standing in water) [Simonsen and Peterson 1977; Ostgaard 1981]. Even minor electrical shocks can cause serious secondary accidents (e.g., muscular reaction to the shock can cause a worker to fall).

c. Noise

Although high noise levels can occur during several types of welding processes (e.g., torch brazing and chipping), they are more often associated with plasma arcs than with any other [National Safety Council 1964]. The high noise levels with plasma arc occur from the passage of heated gas through the constricted throat of the nozzle at supersonic velocities. Noise levels have been measured in the 2,400 to 4,800-Hz range and often exceed 100 dBA. Low-velocity nozzles greatly reduce the noise emitted. The use of induction-coupled plasma jets also greatly reduces the level of noise [National Safety Council 1964]. Levels exceeding 90 dBA have been found in torch brazing operations [NIOSH 1978]. Cresswell [1971] described noise levels of only 70 to 80 dBA from torches using argon-hydrogen mixtures; however, nitrogen and nitrogen-hydrogen mixtures produced levels of 100 to 120 dBA. The same author also noted that cutting materials up to 50 mm thick did not usually pose a noise problem but that thicker materials produced more intense noise levels (levels not given) that required hearing protection.

d. Ionizing Radiation

X-rays are produced as secondary radiation by electron beam welding equipment. The configuration and operating principles of this equipment are similar to those of an X-ray tube [Taylor 1964]. The electrons are generated at the cathode, which is a heated tungsten filament. The electrons are accelerated toward a target by a difference in potential and are focused by using a magnetic field. X-rays are produced when high-speed electrons strike the workpiece, its metal base, or other materials. The intensity and energy of the X-rays are functions of the beam current, the accelerating voltage, and the atomic number of the material on which the beam impinges [Voltkova et al. 1969]. X-radiation may be produced in the electron beam gun itself, at the anode, or in the work chamber wherever the beam strikes a surface. The radiation may be produced any time that power is applied to the high-voltage portion of the equipment.

Radiation may be emitted from the welding equipment at vacuum ports, door flanges, or windows, or from motor shaft and power conduit openings [AWS 1978].

Nonconsumable thoriated tungsten electrodes are usually used in gas tungsten arc welding. The electrodes may contain 1% to 3% thorium oxide, which may potentially emit alpha radiation [Breslin and Harris 1952; Bergtholdt 1961]. Although the electrodes are considered nonconsumable, they are gradually used up. Breslin and Harris [1952] investigated the potential exposure to alpha radiation from thorium during various types of gas tungsten arc welding. Commercially available equipment was used to weld with a 2% thorium oxide electrode; welding operations were performed according to manufacturers' recommendations but without any ventilation. Personal air samples were collected in the operator's breathing zone at the lowest part of the welding helmet. General air samples were also taken at a distance of 1 ft (0.3 m) from the arc. Alpha activity was measured using alpha scintillation counters. No detectable alpha activity was found in the samples. The authors concluded that welding with thoriated tungsten electrodes poses no significant radiation hazard.

e. Radiofrequency Radiation

Radiofrequency (RF) radiation can be used in tungsten inert gas welding to start or continue an arc between the base metal and a nonconsumable tungsten electrode. The frequency of RF radiation in this application is reported to be less than or equal to 5 megahertz (MHz) with a power output of 20 to 30 kilowatts (kW). Since no one has measured the exposure of welders to electric or magnetic field radiation from this type of welding, potential exposure levels cannot be estimated [OSHA 1982].

IV. HEALTH AND SAFETY HAZARDS

A. Introduction

Welding processes are potentially hazardous because they require intense energy to change the physical state of metals. The chemical changes associated with such energy may result in emissions of various toxic fumes, dusts, gases, and vapors; they may also generate exposures to physical agents that include noise, vibration, heat, electrical current, and infrared (IR), visible, ultraviolet (UV), ionizing, and radiofrequency (RF) radiation.

The degree of risk varies with the method and control measures employed, work practices used, metals and fluxes involved, and duration of exposure permitted. Safety hazards encountered on a daily basis complicate working conditions for welders. These conditions have resulted in both major and minor traumatic injuries and in death.

B. Health Hazards

1. Animal Toxicity

a. Introduction

Over the past 40 years, a number of animal studies have examined the acute and subchronic effects of welding fumes and the mutagenic potential of total airborne welding emissions (gases plus fumes). However, only one animal study has investigated the carcinogenicity of welding fumes as a result of long-term exposures [Reuzel et al. 1986]. In this document, the term "welding emissions" refers to a combination of gases plus fumes. Unless otherwise reported, these exposures were generated from shielded metal arc or gas metal arc welding.

b. Acute Effects

In a series of experiments, Titus et al. [1935] exposed groups of animals (1 to 4 cats, 1 to 5 rabbits) for 0.8 to 8.5 hr to iron oxide or to the welding emissions produced during electric arc cutting of iron with iron electrodes. Exposure concentrations ranged from 10 to 350 mg/m^3 (0.3-μm particle size) of fumes, which contained mostly ferric oxide. Concentrations above 275 mg/m^3 were difficult to maintain, since at these increased concentrations, the particles from the fumes aggregated as rapidly as they were produced. To accentuate the effect of fume exposure, carbon dioxide (1% to 14%) was added to chamber air to increase respiration. An additional four groups of rabbits were exposed to arc cutting gases alone, and two other groups were exposed to ferric oxide alone at concentrations comparable with those contained in the fumes. When exposed to high concentrations of either the arc cutting emissions (320 mg/m^3) or gases, animals exhibited severe pulmonary edema, dilation of alveoli, hemorrhage of the lungs, and death. Since higher air concentrations of ferric oxide alone did not cause acute lung pathology or death in exposed animals, the arc cutting gases (unidentified) were considered the probable cause of the observed toxicity. The authors noted that these pulmonary effects induced by the gaseous components of the emissions were similar to those caused by such irritating gases as nitrogen peroxide, ozone, or chlorine.

Senczuk [1967] administered 0.5-ml saline suspensions of welding fumes generated from either acid-, basic-, or rutile-coated electrodes into the stomachs of six white female mice (strain unspecified) per treatment group. The type of metal welded was not stated. The suspension from basic electrode fumes produced lethality at lower doses than did suspensions from acid or rutile fumes. The dose capable of killing 50% of the animals within 48 hr after treatment (LD_{50}) was 755, 5,000, or 5,000 mg/kg for suspended fumes generated from basic-, acid-, or rutile-coated electrodes, respectively. When similar suspensions were intratracheally injected into groups of six white female Wistar rats, the LD_{50}'s for basic, acid, or rutile welding fumes were 132, 762, or 792 mg/kg, respectively. Welding fume composition was analytically determined by an unreported method. The author theorized that the increased toxicity associated with basic electrode fumes was caused by fluorine, which was not present in the other test electrode fumes. Manganese, silicon, and aluminum compounds were considered the toxic components of acid or rutile dusts, whereas sodium and magnesium carbonates and titanium compounds were considered much less toxic. Chromium content was neither determined nor discussed.

Kawada and Iwano [1964] used several animal species to study the acute lethality of emissions from basic and rutile (ilmenite) electrode welding of a steel (composition undefined) plate. Unknown strains of mature male mice, white rats, rabbits, and guinea pigs were subjected to a 1-hr inhalation exposure to emissions from a 1-min burn with a basic electrode. The group sizes and chamber emission concentrations were unspecified. Since lethality was observed only in the guinea pig, the guinea pig was chosen as the test species for further study. A 1-hr inhalation of emissions from a 1-min burn of a basic electrode produced death within 24 hr in 10 of 12 guinea pigs and in 2 of 10 guinea pigs when exposure was to rutile emissions under the same conditions. Upon sacrifice of the survivors from the group exposed to basic fumes (time unspecified), the collective histopathology for the lungs revealed deposits of fumes, blood stasis, edema, pneumonia, atelectasis, and emphysema. However, when an additional group of guinea pigs was exposed only to the gaseous components of basic electrode emission, no deaths occurred. The disposition of these animals was not stated.

Kawada and Iwano [1964] also used additional groups of guinea pigs that were intraperitoneally injected with a constant volume of 2 ml of either a water suspension containing 150 mg of basic or rutile fumes or the supernate or insoluble sediment fractions of a similar suspension. The aqueous suspension of basic electrode fumes killed 15 of 15 guinea pigs within 3.5 hr after injection, whereas the suspension of rutile fumes was nonlethal in 6 of 6 treated guinea pigs. Because rutile fumes were not lethal in guinea pigs, no further testing of soluble or insoluble fractions was conducted. Intraperitoneal injection of the water soluble fraction from basic electrode fumes resulted in the deaths of all six treated animals within 1 hr after injection, but six of six animals survived administration of the water-insoluble fraction. Each active compound present in the water-soluble fraction of basic welding fumes was tested and ranked by decreasing lethal potential as follows: potassium fluoride, potassium acid fluoride, potassium hydroxide, sodium hydroxide, sodium fluoride, and calcium silicofluoride. Since the water-insoluble metal oxides (aluminum, barium, calcium, iron, magnesium, manganese, silicon, or titanium) in these two fumes were not lethal to injected animals, the authors did not consider them to be toxicologically active.

Hewitt and Hicks [1973] exposed male albino SCE strain rats by inhalation to rutile welding emissions at an average concentration of 1,500 mg/m^3. The lungs were analyzed with neutron activation to assess tissue concentrations, rates of uptake, and elimination of inhaled metals. Metal uptake in liver and blood was also assessed. The rutile iron electrode used was coated with limestone, manganese dioxide, kaolin, cellulose powder, and sodium and potassium silicate binders. Two rats were exposed for 30 min, while seven rats were exposed for 4 hr. Tissue concentrations at 24-hr post-exposure were expressed as μg compound/g of freeze-dried tissue. The rats exposed for 30 min had a statistically significant increase ($p<0.05$) of iron (1,175 μg) and cobalt (0.22 μg) in the lung but not chromium (0.01 μg) or antimony (0.01 μg) when compared with controls. The seven rats exposed for 4 hr had a statistically significant increase ($p<0.05$) in iron (7,175 μg), cobalt (0.32 μg), chromium (0.03 μg), and antimony (0.25 μg) in the lung. Additionally, the cobalt concentrations in the liver (0.6 μg) and blood (0.2 μg) were statistically increased ($p<0.05$) after a 4-hr exposure when compared to the controls. Microscopic examination of the treated lungs revealed large numbers of particulate-loaded macrophages in the alveoli and alveolar ducts, slight alveolar epithelial thickening, and peribronchial edema. In a subsequent experiment, eight rats were exposed to welding emissions for 4 hr. Pairs of these animals (and pairs of control rats) were killed 1, 7, 28, or 75 days after exposure. The iron, cobalt, chromium, and antimony contents in the lung progressively decreased over the 75-day period.

The histopathological lung changes that were observed within the first 4 hr of exposure returned to normal following 75 days of no exposure. However, macrophages that contained particulate material continued to be present.

c. Subchronic Effects

The effects of welding emissions on animals have been summarized in Table IV-1. Tollman et al. [1941] performed an inhalation study in which 2 groups of 12 young adult guinea pigs and 10 young adult white rats were exposed for 4 hr/day, 6 days/week. One group was exposed for approximately 29 weeks to partially filtered carbon arc welding emissions, and the other group was exposed for approximately 33 weeks to oxides of nitrogen only. This was followed by a 1-month nonexposure period for guinea pigs. The type of metal welded and filter used were not reported. Fumes passing through the filter were less than 25 mg/m^3 during the total study period. The authors reported that the average concentration of oxides of nitrogen was 107 ppm in the gas phase of the welding emissions. This concentration was comparable to the average concentration of oxides of nitrogen (125 ppm) when administered alone. The investigators found a consistent response in all test groups regardless of the parameter studied. Guinea pigs in both groups had an average loss of 11% to 15% in terminal body weights when compared with their maximum weights attained during the experiment. Similar weight loss data for rats were not given. At the end of 7-1/2 months of treatment, guinea pig mortality reached 67% in the filtered emissions group and 92% in the oxides of nitrogen group, whereas all rats were dead within the first 3.4 months of exposure. Histopathologic examination of tissues revealed the lungs as the primary target organ for both species and all treatment groups. Pulmonary pathology included: epithelial desquamation and necrosis, atelectasis, edema, and pneumonia. The principal differences observed were thicker alveolar walls and more macrophages in the lungs of those animals exposed to filtered welding emissions. No histopathology was specifically cited for the guinea pigs that survived the exposure period. The authors concluded that the effects were primarily due to exposure to oxides of nitrogen rather than to any other component present in carbon arc welding emissions.

McCord et al. [1941] reported on the inhalation exposure of 24 albino rats and 16 rabbits of both sexes (strains, ages, and numbers of each sex not given) to the emissions produced during shielded metal arc welding (unspecified metal) from electrodes that contained mostly silicon (21%) and titanium (42%) dioxides. An equal number of nonexposed rats and rabbits were used as controls. Exposures were for 6 hr/day, 5 days/week for a total of 46 days. This was followed by 43 days of nonexposure before study termination. The total fume concentration was not given; however, four components accounted for over 97%: iron oxide (79%), manganese oxide (5%), silicon dioxide (8.4%), and titanium dioxide (5.4%). The average chamber concentration of nitrogen dioxide was 20-24 ppm, and the average nitrous oxide concentration was 3 ppm, while the average concentrations of ferric oxide, manganese, and silicon dioxide were 465, 16, and 61 mg/m^3, respectively. Titanium dioxide values were

Table IV-1.--Summary of animal studies on the effects of welding emissions

Type of metal	Type of welding (electrode)	Toxic agents (total emissions, gases, or fumes)	Species	Route and duration of exposure	Dose(s)	References
Not reported	Carbon arc (carbon)	Partially filtered emissions or oxides of nitrogen	Guinea pigs and rats	Inhalation 4 hr/day x 6 days/week for up to 200 days exposure (plus a 1-month nonexposure period in guinea pigs only)	Partially filtered emissions: oxides of nitrogen, 107 ppm, plus fumes, <25 mg/m^3 Gas administered alone: oxides of nitrogen, 125 ppm	Tollman et al. [1941]
Summary of effects:	Similar effects were induced for the treatment groups of both species: weight loss, lung pathology (epithelial necrosis or desquamation, atelectasis, edema, and pneumonia) and death.					
Not reported	Shielded metal arc (silicon/ titanium dioxides)	Fumes	Rats and rabbits	Inhalation 6 hr/day x 5 days/week for 46 days exposure plus 43 days of recovery	Total fume concentration not given.	McCord et al. [1941]
Summary of effects:	The treated animals for both test species developed losses in body weights and siderosis (without silicosis). During the nonexposure period the iron concentration in the lungs of treated animals progressively decreased.					

(Continued)

Table IV-1 (Continued).—Summary of animal studies on the effects of welding emissions

Type of metal	Type of welding (electrode)	Toxic agents (total emissions, gases, or fumes)	Species	Route and duration of exposure	Dose(s)	References
Not reported	Shielded metal arc (basic or rutile)	Emissions	Rats and rabbits	Inhalation 3 hr/day x 7/week for 91-110 days plus 130-182 days of nonexposure	Basic: 60 mg/m^3; Rutile: 198-222 mg/m^3	Byczkowski et al. [1970]

Summary of effects: Rats and rabbits had approximately equal capacities to clear fume metals deposited in trachea and lung. Iron clearance from tissues was still incomplete at end of nonexposure period.

Type of metal	Type of welding (electrode)	Toxic agents (total emissions, gases, or fumes)	Species	Route and duration of exposure	Dose(s)	References
Mild steel	Shielded metal arc (basic)	Emissions	Rats	Inhalation 1 hr/day x 5 days/week for 1, 2, 3, or 4 weeks with sacrifice 24 hr after last exposure or 1 hr/day x 5 days/week x 4 weeks plus 106 days of nonexposure	Basic or rutile: 43 mg/m^3	Kalliomaki et al. [1983]
Stainless steels	Shielded metal arc (rutile)	Emissions	Rats	Inhalation 1 hr/day x 5 days/week for 1, 2, 3, or 4 weeks with sacrifice 24 hr after last exposure or 1 hr/day x 5 days/week x 4 weeks plus 106 days of nonexposure		

Summary of effects: Both emissions induced metal deposition in the lungs directly proportional to the metal content in the emissions. Slow lung metal clearance times ($T_{1/2}$) were up to 50 days.

(Continued)

Table IV-1 (Continued).—Summary of animal studies on the effects of welding emissions

Type of metal	Type of welding (electrode)	Toxic agents (total emissions, gases, or fumes)	Species	Route and duration of exposure	Dose(s)	References
Not reported	Shielded metal arc (rutile)	Emissions	Wistar rats	Inhalation 3 hr/day x 13 weeks plus 26 weeks of recovery	222 mg/m^3	Senczuk [1967]

Summary of effects: Exposure to shielded metal arc emissions produced different weight gains in treated and control rats, -2% and +18%, respectively; however, the lung weights were similar. During the nonexposure period, the weight gain in treated and control rats was +2% and +29%, respectively, while treated lung weights were 18% heavier than controls.

Type of metal	Type of welding (electrode)	Toxic agents (total emissions, gases, or fumes)	Species	Route and duration of exposure	Dose(s)	References
Not reported	Shielded metal arc (high silicon/high iron oxide)	Emissions	Guinea pigs	Inhalation 4 hr/day x 6 days/week for 110 days	High or low silicon: 18-36 mg/m^3	Garnuszewski and Dobrzynski [1966]
	Shielded metal arc (low silicon/high iron oxide)	Emissions	Guinea pigs and rabbits	4 hr/day x 6 days/week x 26 weeks plus 4-mo nonexposure for guinea pigs only		

Summary of effects: All treated groups of animals had siderosis. For high silicon oxide electrode emissions the guinea pigs had silicosis and pneumoconiosis of the interalveolar septa which also had nodules containing collagen fibers and silica particles. Exposure of guinea pigs to low silicon oxide electrode emissions induced little silicosis and few small pneumoconiotic nodules that had less collagenous fiber and silica particle contents when compared to a high silica exposure group. Following a 4-month nonexposure period, these pulmonary lesions did not regress. Rabbits exposed to low silicon oxide emissions had only thick interalveolar septa.

(Continued)

Table IV-1 (Continued).--Summary of animal studies on the effects of welding emissions

Type of metal	Type of welding (electrode)	Toxic agents (total emissions, gases, or fumes)	Species	Route and duration of exposure	Dose(s)	References
Stainless steel	Shielded metal arc (undefined) Gas metal arc (un-coated wire)	Fume suspensions in saline	Hamsters	Tracheal intubation 1 day/week x 56 plus 44 weeks nonexpo-sure; except 2.0 mg level for shielded fume which was dosed once a week for 25 weeks, then once every 4 weeks for 31 weeks	Shielded metal arc fume: 0.5 or 2.0 mg/inj. Gas metal arc fume: 2.0 mg/inj. Calcium chromate positive control: 0.1 mg/inj. Saline negative control: 0.2 ml/inj.	Reuzel et al. [1986]

<u>Summary of effects</u>: Shielded metal arc fumes induced one lung cancer at each dose. No lung cancers were found in the gas metal arc fume or calcium chromate, saline, and historical control groups.

not cited. Average weight gains for exposed versus nonexposed groups were 272 g versus 366 g for rabbits and 2.9 g versus 32 g for rats. Siderosis of the lungs was the only biologically significant pathology present in all of the exposed animals sacrificed at the end of the experiment, with the earliest detection of siderosis observed in a rat that died after 22 days of exposure. No silicosis was found in any of these animals.

Byczkowski et al. [1970] reported on the metal concentrations in the lungs of 290 rats and 30 rabbits exposed by inhalation to emissions generated during the melting of basic or rutile electrodes. The effect of exercise on the retention of inhaled metals from rutile welding emissions was also studied in rats. Baseline metal concentrations were determined in an unstated number of animals from each treatment group before the start of the exposure period. Groups of young adult male Wistar rats and 1-year-old albino rabbits (group sizes not specified) were exposed to approximately 60 mg/m^3 of basic welding emissions, while a group of rats was exposed to 198-222 mg/m^3 of rutile welding emissions. In addition, one similarly exposed rutile welding group was exercised by being housed in cages that rotated during two of the 3-hr daily exposures. Exposures for the remaining groups were 3 hr/day, 7 days/week for 91 to 95 days for rats and 110 days for rabbits. During the period of time in which the animals were being exposed, an undefined number of surviving animals in each treatment group were withdrawn from exposure for terminal assessment of changes in lung metal content. Final sacrifices occurred 130 days after termination of exposures for rats and rabbits in the basic welding emissions groups and after 182 days for rats in the rutile welding emissions group.

Rats sacrificed after 95 days of exposure to welding emissions from basic electrodes had total lung tissue contents of 0.57 mg fluorine, 4.95 mg manganese, and 223 mg iron. Similarly exposed rabbits sacrificed at the end of 110 days had lower total lung contents of 0.32 mg fluorine, 4.2 mg manganese, and 103 mg iron when compared to the rats. Tracheal tissue concentrations for fluorine in rats and rabbits were five times higher (2.79 mg and 1.76 mg, respectively) than those found in the lung tissue. The groups of rats and rabbits that were exposed to the same basic welding emissions and removed from exposure for 130 days, had up to a 50% decrease in fluorine and iron levels and over an 80% decrease in manganese from those determined after 95 and 110 days. The group of rats exposed to rutile welding emissions had the following total lung metal contents at the end of the 91- to 95- day exposure period: silicon, 0.45 mg; titanium, 0.117 mg; manganese, 0.495 mg; and iron, 9.3 mg. When these values for the rutile exposure group were compared to those in a similarly exposed but exercised group, exercise increased the metal concentrations by approximately 50%. No analysis was performed for lung metal content during the 182 days that followed the termination of exposure. However, unexercised rats withdrawn from rutile fume exposure for 182 days had approximately a 50% decrease in silicon, titanium, and manganese concentrations but only a 23% decrease in iron.

Kalliomaki et al. [1983] exposed adult male Wistar rats (300±15g) to emissions generated from shielded metal arc welding of either mild steel with basic electrodes or stainless steel with rutile electrodes. The purpose of the study was to determine which metals (iron, manganese, chromium, or nickel) contained in the two types of welding emissions were retained by or cleared from the lung. A total of 52 rats in groups of 2 rats or less was used in 14 treatment and 14 control groups. Each treatment group was exposed to 43 mg/m^3 of emissions. Four of the treatment groups were designed to determine retention of metals in animals exposed for 1 hr/day, 5 days/week for 1, 2, 3, or 4 weeks with sacrifice of a treatment group and a control group 24 hr after last exposure. The animals in the remaining 10 groups were exposed for 1 hr/day, 5 days/week for 4 weeks and were evaluated for clearance of metals. Following the last exposure, a treatment group and a control group were sacrificed at the following time intervals: 1, 3, or 8 hr and 1, 4, 8, 14, 28, 56, or 106 days.

Basic electrode welding of mild steel produced emissions that contained 20% iron and 2.8% manganese by weight but only trace amounts of chromium and nickel (remaining fraction unstated). In rats exposed to these emissions, the lung tissue retention rates for iron and manganese each became saturated by the third week of exposure with initial retention rates of 28 and 4 μg/g dry lung tissue/hr, respectively. Clearance time was measured as the time required to decrease the tissue load of a metal by 50% ($T_{1/2}$). These metals had fast and slow clearance times for their curves. Fast clearance $T_{1/2}$ times were 6 days for iron and 0.5 days for manganese; slow clearance $T_{1/2}$ times were 35 for iron and 4.3 days for manganese. Because chromium and nickel were present in only trace amounts in mild steel welding fumes, clearance times for these elements were not determined.

Rutile electrode welding of stainless steel produced emissions which contained 4.0% iron, 2.2% manganese, 3.0% chromium, and 0.4% nickel by weight (remaining composition unstated). In rats exposed to these rutile emissions, the retention curves were linear with initial rates of 4.8 (iron), 2.8 (chromium), and 0.3 (nickel) μg/g dry lung tissue/hr. The retention of manganese reached saturation after 19 hr of exposure, with an initial retention rate of 1.5 μg/g dry lung tissue/hr. Slow clearance $T_{1/2}$ times were 50 days for iron, 40 days for chromium and manganese, and 30 days for nickel. These metals did not have fast clearance times.

Senczuk [1967] used 3-to 4-month-old Wistar rats to study the toxicity of inhaled emissions produced by welding (metal unspecified) with rutile electrodes. A treatment group of 120 male rats was exposed to an average emission concentration of 222 mg/m^3 for 3 hr/day for 13 weeks. The control group consisted of 30 nonexposed young adult male rats. Interim sacrifices within the exposure group occurred after 2, 4, 6, 8, 11, and 13 weeks, and 2 and 5 weeks postexposure. Similar interim sacrifice intervals were used for the control group with the omission of those during exposure weeks 2, 6, and 11 and postexposure week 2. Twenty-six weeks after cessation of exposure, the remaining survivors (number unstated) were sacrificed. Mortality within the groups was not reported. Analysis of chamber emissions demonstrated concentrations of 102 mg/m^3 ferric oxide, 15.2 mg/m^3 silicon, 9.4 mg/m^3 manganese, 3.5 mg/m^3 titanium dioxide, and 8 mg/m^3 oxides of nitrogen. Examination of the growth curves showed that the exposed rats progressively lost 2% body weight during the 13-week treatment period. During the 5 weeks following the 13-week exposure period, their body weight gain was parallel to that of the controls, after which it began to decrease. Twenty-six weeks after the 13-week exposure period, the animals' terminal body weights were compared with their preexposure weights. The results showed that the treated rats had a 2% gain while the controls had a 29% gain. Lung weights (dry) from treated and control rats were approximately equal at the end of the exposure period; however, the lung weights (dry) of the treated rats sacrificed 26 weeks following the exposure period were 18% heavier than those of the corresponding controls. Because the lungs were desiccated for weighing, histopathologic evaluations were not performed.

Garnuszewski and Dobrzynski [1966] compared the pulmonary effects of inhalation of welding emissions on guinea pigs and rabbits (strain, age, and sex unreported). Two types of electrodes were used to generate the test emissions, but the type of metal welded was not reported. One type, EP52-28p, had high silicon oxide (25.5%) and high ferric oxide (18%) contents, while the other, EP47-28p, had low silicon oxide (7.8%) but high ferric oxide (23%) levels. Comparative pathology of animal tissues was used to determine if exposure to the welding emissions from the low silicon oxide electrode was biologically safer than that from the high silicon oxide electrode.

The first experiment included a total of 72 guinea pigs exposed to high silicon oxide emissions; half of the group was exposed to emission concentrations of 18 mg/m^3, while the other half was exposed to 36 mg/m^3. The emissions were generated from the high silicon oxide electrode and the experiments carried out 4 hr/day, 6 days/week for 110 days. A total of 10 guinea pigs comprised the nonexposed (undefined) control group. Although the number of animal deaths per treatment group was not stated, the combined total was 30 of 72. Guinea pigs exposed to either emission concentration had a mixed type of pneumoconiosis (e.g., siderosis coexisting with silicosis as manifested by pneumoconiotic nodules containing collagenous fibers and silica particles). Phagocytes containing silica and iron oxide particles were found in abundance throughout the trachea, bronchi, and interalveolar septa and lumen. The above findings were all concentration-related in intensity.

In the second experiment, 50 guinea pigs and 10 rabbits were exposed to the emissions from the low silicon oxide electrode. The animals were divided into 2 equal groups and exposed 4 hr/day, 6 days/week for 6 months to the same emission concentrations as in the first experiment. Scheduled sacrifices occurred after 6 months of exposure followed by 1 and 4 months of nonexposure. The control groups included 10 guinea pigs and 2 rabbits. During exposure, the combined mortality for both guinea pig exposure groups was 25 of 50. These low silicon oxide exposures produced fewer and milder pulmonary effects than those observed in the animals of the high silicon groups for the first experiment. The changes were limited to the alveolar septa and alveoli which were thin and sometimes ruptured. All exposed guinea pigs were found to have siderosis, but little silicosis. If nodules were present, they were small and few in number when compared to those induced by high silicon oxide electrode emissions. These small nodules contained fibroblasts, histiocytes, and cells with low amounts of silicon, but did not contain pronounced amounts of collagenous fibers. Because similar histopathology effects were present in tissues from guinea pigs sacrificed after the nonexposure periods, the induced effects were not considered readily reversible. The exposed rabbits had siderosis including slightly thickened interalveolar septa that had few dust-containing cells. Neither collagenous fiber proliferation, silicotic nodules, nor silica particles were observed in rabbit lung tissues. The authors concluded that the emissions from the low silicon oxide electrode were biologically less hazardous than those from the high silicon oxide electrode.

d. Mutagenicity

Welding emissions from shielded metal arc and gas metal arc welding on mild and stainless steels as well as some of the individual metals contained in the emissions have been tested for their potential to induce adverse mutagenic changes in DNA through use of in vitro (bacterial or cell culture) assays, or in vivo (animal) test systems. In bacterial and cell culture tests, the test agent is added to microbiological or tissue culture media, respectively, while in animal tests the agent is administered to live animals. The in vitro and in vivo tests are used as predictors of a chemical agent's potential to induce cancer through genetic changes in exposed animals or humans.

(1) Mild Steel--Bacterial and Cell Culture Studies

Hedenstedt et al. [1977] found the fumes to be nonmutagenic from basic or rutile electrode for shielded metal arc welding and the solid wire or powder-filled rutile electrode for gas metal arc welding of mild steel. E. coli W3110 (pol A^+) and E. coli p3478 (a pol A^- derivate) and S. typhimurium (TA 100), with and without metabolic activation were used in the study. The weight of fume tested per plate ranged from 100 to 1,250 μg.

Maxild et al. [1978] also found that the fumes from rutile shielded metal arc and gas metal arc welding on mild steel were nonmutagenic in the TA 98 and TA 100 test strains of S. typhimurium with or without metabolic activation. The dry weight of fume suspended in dimethylsulfoxide (DMSO) solvent and added to each test plate ranged from 0.1 to 8 mg.

Shielded metal arc fume from mild steel welding was also confirmed to be nonmutagenic by Stern et al. [1982] following testing in S. typhimurium TA 100 with and without metabolic activation. The types of electrodes used to generate the fume and the weight of fume tested per plate were not reported.

Niebuhr et al. [1980] collected gas metal arc fume from the welding of mild steel when solid nickel electrodes were used. A modified sister chromatid exchange (SCE) assay was used to detect mutations. The presence of nickel in the welding fume induced increases in SCEs that were directly proportional to the amount of nickel biologically available in the test media. Concentrations of water- or serum-soluble nickel that ranged from 2.5 to 10 μg/ml yielded SCEs that ranged from 7.3 to 9.4/cell compared to a control value of 8.4/cell. Although mild steel welding fumes devoid of nickel and chromium(VI) compounds were inactive in bacterial mutagenesis assays [Hedenstedt et al. 1977; Maxild et al. 1978; Stern et al. 1982], the addition of nickel into the fumes produced a slight increase in mutagenic activity in the SCE assay.

Hansen and Stern [1983] used the baby hamster kidney cell (BHK-21) assay to determine the ability of gas metal arc fumes generated from welding with a pure nickel wire electrode to transform colonies. In addition, pure nickel oxides, water soluble nickel acetate, and water insoluble nickel subsulfide were tested. They found that welding fumes and all the tested nickel compounds transformed the BHK-21 cell line.

(2) Stainless Steel

(a) Bacterial and Cell Culture Studies

Hedenstedt et al. [1977] studied the mutagenic potential of fumes generated during either shielded metal arc welding (rutile electrodes) or gas metal arc (solid wire electrodes) welding of stainless steels in E. coli and S. typhimurium bacterial test systems. E. coli W3110 (pol A^+) and E. coli p3478 (a pol A^- derivate), and S. typhimurium (TA 98 and TA 100 strains) were used. All bacterial test systems were studied with and without a liver microsomal metabolizing system (S-9 mix). Both types of welding fumes were mutagenic in the absence of S-9 mix, regardless of bacterial strain employed; however, at equal plate concentrations shielded metal arc welding fumes were more mutagenic than gas metal arc fumes. In addition, all water soluble fume fractions were mutagenic. The magnitude of these mutagenic effects were proportional to the degree of water solubility of the hexavalent chromium compounds present in the two types of stainless steel welding fumes.

The hexavalent chromium content in shielded metal arc welding fumes was significantly higher (10 to 1000 times) than that present in gas metal arc fumes. In S. typhimurium, metabolic inactivation of the mutagenic effects for shielded metal arc fumes required both S-9 mix plus an NADP generating system. For all bacterial strains tested, similar inactivation of gas metal arc fumes required the S-9 mix alone. The authors suggested that the mutagenic potential for both types of stainless steel welding fumes may have been due to their water soluble hexavalent chromium content. However, if different chromium compounds were present in shielded rather than gas metal arc fumes, it would explain why they had dissimilar metabolic requirements for mutagenic inactivation.

Maxild et al. [1978] investigated the mutagenic potential of stainless steel welding fumes by utilizing TA 98 and TA 100 strains of S. typhimurium with and without metabolic activation. The dry weight of shielded metal arc welding fume suspended in DMSO solvent and added to each test plate ranged from 0.1 to 8 mg. Based on the weight of fumes required to double the mutation frequency in these bacterial strains, with or without a liver microsome metabolizing system (S-9 mix), shielded welding fumes were more mutagenic than gas metal arc fumes. The mutagenic activity was reduced for both types of fumes when S-9 mix was used. Regardless of the state of activation, the number of mutations induced by these fumes was increased in a dose-related manner. The authors stated that the amount of fumes produced by shielded metal arc welding was 3 to 6 times greater than that produced by gas metal arc welding. Fume analyses revealed that the fumes from shielded metal arc welding contained 330 times more soluble chromium (valence state unspecified) than did gas metal arc welding fumes.

The amount of welding fumes required to double the mutation rate of the S. typhimurium TA 100 (LT2) bacterial strain was also studied by Pedersen et al. [1983]. The activity was equalized on the basis of the chromium content of aqueous extracts (assumed to be chromium[VI]) of shielded and gas metal arc welding fume versus a chromium(VI) positive control solution (sodium dichromate). The authors did not define the types of welding electrodes used to generate the fume. They established that 9 μg of water-soluble chromium(VI) in shielded metal arc welding fumes, 5 μg of water-soluble chromium(VI) in gas metal arc fumes, and 10 μg of water-soluble sodium dichromate (chromium[VI]) per plate caused mutations to double. The authors concluded that the mutagenic potential of stainless steel welding fumes can be completely accounted for on the basis of their chromium(VI) content.

Stern et al. [1982] used the S. typhimurium TA 100 assay in dose-response experiments and factorial design studies to show that the mutagenic activity present in welding fumes is caused by its soluble chromium(VI) content. When mutagenic activity was expressed as revertants/mg/plate, shielded metal arc welding fumes were more mutagenic than gas metal arc fumes. However, when it was expressed as specific activity (number revertants/μg soluble chromium(VI)/plate), gas metal arc fumes were the more mutagenic of the two types of fumes. The authors concluded that the soluble chromium(VI) content of gas metal arc fumes could be partially reduced to insoluble chromium(VI), and to chromium(III) when reducing substances (aluminium and magnesium) were present. When compared to gas metal arc fumes, the specific activity of chromium(VI) in shielded metal arc welding fumes was reduced by components unique to these fumes. They also observed that when fumes containing chromium(VI) were suspended in water, chromium(VI) was contained in both the water soluble and insoluble phases; however, only the water soluble phase was mutagenically active. The authors stated that data from experiments with synthetic fumes demonstrated that neither the manganese nor the nickel content of stainless steel welding fumes was mutagenic nor did these metal compounds act in an antagonistic or synergistic manner when in the presence of fumes containing chromium(VI).

Hedenstedt et al. [1977] used mammalian cells--the V-79 Chinese hamster cell assay--to detect the mutagenic potential (6-thioguanine resistance) of stainless steel welding fumes. The water soluble fraction of rutile electrode fumes from stainless steel welding produced a significant increase ($p<.01$) in the number of 6-thioguanine resistant mutants when compared to the negative controls.

Koshi [1979] also used a mammalian cell assay--a pseudo-diploid Chinese Hamster cell line--to investigate the mutagenic effect of shielded metal arc versus gas metal arc welding fumes from mild and stainless steels, respectively. This assay was used to determine the frequencies of SCEs. In addition, Koshi studied the metallic composition of these two types of generated fumes and their solubilities in water and in culture medium.

Koshi [1979] found dose-related increases for SCEs for both shielded and gas metal arc welding fumes; however, it took 50 times more weight for the gas metal arc fumes than for shielded metal arc fumes to produce a doubling of the control background rate (5.3 SCE/cell). The lower potency of gas metal arc fumes was directly proportional to the decreased water solubility of its chromium(VI) component. When the frequency of SCEs/cell was compared for equivalent chromium contents, the authors stated chromic acid, a chromium(VI) component, was the most active followed by shielded metal arc fumes and then gas metal arc fumes; however, they presented other data which support equal activities also. Since water soluble nickel, manganese, or chromium(III) compounds present in the two types of fumes were mutagenically inactive, the authors concluded that the active mutagen was chromium(VI). The induction of increased chromosome aberrations in the form of chromatid gaps and chromatin exchanges were similarly ascribed to the chromium(VI) content in both types of welding fumes tested.

(b) Animal Studies

Knudsen [1980] performed a mammalian spot test in female mice to detect genetic mutations through changes in hair color. T-stock males (homozygous for four recessive coat-color mutations) were mated with C57BL females (homozygous wild-type for the mutations carried by T-stock males). The pregnant C57BL mice were administered suspensions of shielded metal arc welding fumes from stainless steel or doses of potassium chromate (positive control) containing approximately 0.5 to 1.5 times the chromium(VI) content of the fume fraction tested. The type of electrode used for fume generation was not described. The mice were intraperitoneally injected with the test materials on days 8, 9, and 10 of gestation. The offspring were checked for spots of recessive hair color at the end of 2, 3, 4, and 5 weeks of age. The shielded metal arc welding fumes produced the same number of spots as approximately equivalent doses of chromium(VI). The authors suggested that the positive mutagenic effect induced by shielded metal arc welding fumes was primarily caused by its chromium(VI) content.

e. Carcinogenicity

Reuzel et al. [1986] investigated the toxicity of welding fumes intratracheally instilled into the lungs of hamsters. Fumes were produced either from shielded electrodes used during metal arc welding or from wire metal electrodes used during gas metal arc welding of stainless steel. The welding fumes were collected onto filters. Each of five treatment groups contained 35 male Syrian golden hamsters. Dosage quantities of fumes were suspended in 0.2 ml of saline for intratracheal injection. The treatment concentrations were 0.5 and 2.0 mg for two shielded welding groups, 2.0 mg for one gas metal arc welding group, 0.1 mg calcium chromate for a "positive control" group (calcium chromate has not been shown to be carcinogenic in this test system), and 0.2 ml of saline for the unexposed control group. The treatment groups were dosed once weekly for 56 weeks, except that the 2.0 mg shielded welding group developed early body weight loss and a few hamsters died; therefore, from weeks 26 through 56, single doses were injected only on every fourth week. Autopsies for all groups were performed after 100 experimental weeks. The chromium contents of the fume from shielded metal arc and gas metal arc welding fumes were 5% and 0.4%, respectively. The nickel content in shielded metal arc fumes was 0.4% while that for gas metal arc fumes was 2.4%. Although not stated by the authors, the total amount (mg/hamster) of chromium injected during the study was calculated as 1.4 (low dose) and 3.3 (high dose) for the shielded metal arc welding fume groups; 0.45 (low dose) and 5.6 (high dose) for the gas metal arc fume groups, and 1.85 for the calcium chromate positive controls.

Although lung weights of hamsters treated with either 2 mg shielded metal arc fumes or 2 mg gas metal arc fumes were significantly heavier (level unstated) than control lung weights; the heaviest lung weights occurred in the gas metal arc fume group. Regardless of treatment or dose level, hamsters that died and those that survived through the nonexposure period following treatment differed little in histopathology or in the number of dust particles present in lungs. This indicated that little recovery had occurred during this period. However, those hamsters in the 2 mg treatment group exposed to gas metal arc welding fumes had the greatest degree of induced pulmonary pathology. This included moderate to severe nonspecific pneumonia, slight to moderate interstitial pneumonia, moderate alveolar bronchiolization, and slight emphysema. Animals dosed with 0.5 mg shielded metal arc welding fumes and those that received calcium chromate showed similar but less pronounced changes.

Two lung cancers were found in the shielded metal arc welding treatment groups. One cancer (a well-differentiated combined epidermoid and adenocarcinoma type) was found in the lung of an animal that was treated with 2.0 mg of shielded metal arc fumes and sacrificed at the end of the 100-week study. The second cancer (an anaplastic tumor, probably a carcinoma, which had metastasized to the surrounding lung parenchyma and mediastinum) was found in the lung of a hamster that died after one year of treatment with 0.5 mg of shielded metal arc fumes. The investigators believed these two tumors were induced by the shielded metal arc welding fumes and were toxicologically significant because neither noncancerous nor cancerous tumors had been observed either in the concurrent controls or in nearly 800 historical laboratory controls. Because pulmonary tumors were not present in the positive control (calcium chromate) animals, the investigators theorized that compounds other than chromium in welding fumes were probably responsible for the induction of the cancers in the shielded metal arc welding fume groups.

f. Summary--Animal Toxicity

Shielded metal arc welding fumes and gases have caused severe acute lung damage (e.g., edema, hemorrhage, pneumonia, and atelectasis) [Titus et al. 1935; Kawada and Iwano 1964; Hewitt and Hicks 1973]. Basic electrode welding of nonstainless steels that did not contain chromium or nickel has produced fumes that are potentially more lethal than those produced by welding of the same metal with acid or rutile electrodes [Senczuk 1967]. It appears that the increased toxic potential of the fumes generated while welding with basic electrodes can be ascribed to the high fluoride content that is absent in either acid or rutile-type electrodes.

Subacute toxicologic studies have demonstrated that irreversible chronic lung disease can result in animals repeatedly exposed by inhalation to welding fumes and gases. Tollman et al. [1941] investigated the pulmonary effects in animals repeatedly exposed to welding gases (oxides of nitrogen). Concentrations which induced mortality also caused lung tissue damage (edema, atelectasis, pneumonia, and necrosis). In addition, the subacute effects of total welding emissions (gases plus fumes) generated during the welding of nonstainless steels were studied in animals by Garnuszewski and Dobrzynski [1966] and Senczuk [1967]. In general, these investigators found that exposure of animals to welding emissions induced premature mortality, suppression of weight gain, fibrotic lung disease, and pneumoconiosis in surviving animals. Siderosis and silicosis resulted from exposures to emissions which contained iron or silicon, respectively. This fibrotic pulmonary pathology was found irreversible during nonexposed periods despite recovery times that sometimes exceeded the length of treatment.

Pulmonary deposition and clearance rates for metals contained in emissions generated during the welding of nonstainless and stainless steels were investigated in animals by several authors (McCord et al. 1941, Byczkowski et al. 1970; Kalliomaki et al. 1983). They found the rates of metal deposition in exposed lungs to be proportional to the metal contents in the emissions. These deposition rates were further increased in animals with concomitant exercise during exposure. For some metals with slow clearance rates, even prolonged periods of nonexposure did not permit complete elimination.

In a wide variety of in vitro and in vivo mutagenesis assays, mild steel welding fumes had little to no mutagenic potential, whereas stainless steel welding fumes were consistently mutagenic.

Shielded metal arc welding of stainless steel produced three to six times more fumes "per mass of weld metal" than gas metal arc welding. The shielded metal arc welding fumes were more water soluble than the gas metal arc welding fumes [Maxild et al. 1978]. The water-soluble fraction of these fumes was shown to be mutagenically active [Hedenstedt et al. 1977; Koshi 1979; Stern et al. 1982; Pedersen et al. 1983], but the water-insoluble fraction had no significant mutagenic activity [Stern et al. 1982]. Assays have demonstrated that much of the mutagenic activity may be ascribed to the chromium(VI) in the water-soluble fraction [Stern et al. 1982]. However, when the mutagenic potentials for these fumes were compared on an equivalent chromium(VI) basis, gas metal arc welding fumes produced four times more mutations in bacteria than did shielded metal arc welding fumes [Stern et al. 1982]. Yet SCE data were equivocal for these two types of fumes [Koshi 1979].

In addition, it appears that compounds other than chromium(VI) could also be active in the water soluble fractions of fumes generated from the two welding processes. This is based on the fact that when the water soluble fractions of both fumes were tested in a metabolically activated S. typhimurium mutagenicity assay, only shielded metal arc fumes lost their metabolic potency [Hedenstedt et al. 1977; Stern et al. 1982].

One 2-year carcinogenicity study has been reported for Syrian golden hamsters that were intratracheally injected with saline suspensions of stainless steel welding fumes [Reuzel et al. 1986]. Lung cancer was observed in one animal from each of the two dose groups that were intratracheally injected with shielded metal arc welding fumes. No cancers were observed in the gas metal arc fume treatment group or the calcium chromate, saline, and historical control groups. Despite the fact that there were only two cancers observed, the authors concluded that these tumors were biologically significant based on the absence of tumors in the calcium chromate (positive control) group and the concurrent and historical nonexposed control groups. However, some question exists concerning calcium chromate being considered as a positive control since: (1) no published experimental data shows the induction of any kind of cancers in hamsters when calcium chromate is intratracheally administered, and (2) the number of animals and dose used for the calcium chromate positive control group may not have been large enough to detect a positive carcinogenic response in these animals.

2. Human Toxicity

a. Pulmonary Effects

This section evaluates case reports and epidemiologic studies that document the adverse respiratory effects reported for workers who are associated with various types of welding processes. The studies are presented in order of the severity of the effects they report, beginning with those that discuss the acute effects associated with exposure to welding fumes and gases (e.g., metal fume fever and pneumonitis) and ending with studies that suggest a risk of respiratory cancer. The data from these investigations are summarized in Tables IV-2, IV-3, and IV-4. Although many of the studies have shortcomings (e.g., the absence of information on types and concentrations of specific chemical agents or on smoking habits), they collectively demonstrate the consistency of the many respiratory diseases in welders.

(1) Nonmalignant Pulmonary Diseases

(a) Metal Fume Fever

Metal fume fever is an acute respiratory disease that is usually of short duration; it is caused by the inhalation of metal oxide fumes that are typically 0.2 to 1.0 μm in particle size (Papp 1968). Although several metals are

In addition, it appears that compounds other than chromium(VI) could also be active in the water soluble fractions of fumes generated from the two welding processes. This is based on the fact that when the water soluble fractions of both fumes were tested in a metabolically activated S. typhimurium mutagenicity assay, only shielded metal arc fumes lost their metabolic potency [Hedenstedt et al. 1977; Stern et al. 1982].

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Table IV-2.—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
Metal fume fever:			
Ross 1974	Shielded metal arc	Acute exposure. Covered electrode contained nickel; mixed fume composition (e.g., iron, calcium, fluoride, silica, aluminum, copper, nickel, etc.)	Tightness of chest, profuse sweating followed by metal fume fever and pneumonia a few days after exposure.
Johnson and Kilburn 1983	Torch brazing	Acute exposure from using several filler metals containing zinc, cadmium, copper, and mild steel.	Eye irritation, headache shortly after exposure followed by muscular pain, chills, chest tightness, malaise, and shortness of breath. Blood leukocyte count and body temperature increased within 24 hours of exposure. Chest radiograph indicated nodular densities.
Pneumonitis resulting from metal fumes:			
Patwardhan and Finckh 1976; Blejer and Caplan 1969; Winston 1971; Beton et al. 1966; Christensen and Olson 1957; Townshend 1968	Brazing or argon arc welding with silver-cadmium alloy; cutting/welding cadmium coated metal	Acute exposure to cadmium fumes (generally in poorly ventilated areas). Exposure concentrations unknown.	Respiratory distress, fever, chills, and pulmonary edema occurring over a period of several days and sometimes resulting in death.

(Continued)

Table IV-2 (Continued).--Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Pneumonitis resulting from metal fumes:</u>			
Jindrichova 1976	Shielded metal arc welding	Three specific groups of welders acutely exposed to various concentrations of chromium and nickel.	Respiratory distress, cough, pulmonary edema, erosion of nasal septum, chronic atrophic rhinitis.
Herbert et al. 1982	Electric arc welding	Acute exposure to aluminum and iron fume.	Diminished FEV, FVC, and total lung capacity, and chronic interstitial pneumonia.
<u>Pneumonitis resulting from gases:</u>			
Mangold and Beckett 1971	Silver brazing	Acute exposure to potassium fluoride and silver/copper. Poor ventilation.	Pulmonary edema.
Maddock 1970	Oxyacetylene torch	Acute exposure to nitrogen dioxide: >100 ppm. Poor ventilation in confined space.	Pulmonary edema followed by death the following day.
Molos and Collins 1957	Argon-oxygen shielded arc welding	Acute exposure to ozone: 2.6 ppm (average). No exposure to fume reported.	Respiratory tract irritation, fatigue, headaches, and shortness of breath.

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Table IV-2 (Continued).--Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
Pneumonitis resulting from gases:			
Challen et al. 1958	Gas tungsten arc welding	Acute exposure to ozone: 0.8-1.7 ppm. No exposure to fume reported.	Respiratory irritation, eliminated when ozone concentration was reduced to 0.2 ppm.
Kleinfeld et al. 1957	Gas metal and tungsten arc welding	Acute exposure to ozone: 9.2 ppm (average). No exposure to fume reported.	Radiographs revealed diffuse peribronchial infiltration consistent with multilobular pneumonia.
Pneumoconiosis including siderosis:			
Enzer and Sander 1938	Arc welding	Chronic mixed-fume exposure for 7-12 years. Poor ventilation. No exposure data.	Lung nodulations with iron deposited around bronchi, in the lymphatic vessels and alveolar septa. No reported parenchymatous changes or fibrosis.
Stettler 1977	Arc welding	Chronic exposure to fume containing iron, chromium, manganese, and nickel from stainless steel welding. Same composition found in lung biopsy.	Two welders examined: one worker welded in open spaces while the other welded in confined spaces. Both had pulmonary fibrosis; the welder who worked in the confined spaces had severe respiratory impairment with extensive interstitial fibrosis.

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Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Pneumoconiosis including siderosis:</u>			
Brun et al. 1972	Arc welding	Welder worked 16 years with stainless steel. Poor ventilation; no exposure data.	Dyspnea, rales, intraalveolar fibrosis, bilateral micronodular reticulation; siderophages in sputum.
Dreesen 1947	Arc welding	Chronic exposure to iron oxide, zinc, other metals. Iron oxide: >20 mg/m^3; zinc: >12 mg/m^3. Poor ventilation and confined spaces.	Siderosis diagnosed in 3% of welders and none in other workers (medical examination of 4,650 workers, 70% welders).
Marchand et al. 1964	Arc welding	No exposure data.	Pneumoconiosis radiologically diagnosed in 25 out of 402 welders (7%). Siderosis classified in 7 of the 25 welders.
Stanescu et al. 1967	Arc welding	No exposure data.	Siderosis suggestive in radiographs of 16 welders while not revealed in 13 nonwelders.
Meyer et al. 1967	Arc welding	Worked with low/high alloys and stainless steel and nonferrous metals.	Massive conglomerate fibrosis (one welder, 24 years exposure).

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Table IV-2 (Continued).--Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Pneumoconiosis including siderosis:</u>			
Kleinfeld et al. 1969	Oxyfuel cutting and shielded metal arc welding	Chronic exposure to iron oxide exposures up to 1.7 mg/m^3 inside helmet and up to 12 mg/m^3 in work environment.	Radiographic examination revealed nodular shadows in lungs (8 of 25 welders) and siderosis in those welders employed longer than 20 years.
Attfield and Ross 1978	Gas metal and gas tungsten arc welding	No exposure data.	Lung opacities (up to 3 mm diameter) were noted in 8 out of 661 welders.
Levy and Margolis 1974	Oxyacetylene cutter	Welder worked 5 years in a steel foundry--respirable silica (6.82 mg/m^3) and iron oxide (19.4 mg/m^3) exposures in work area.	Radiographic examination revealed a reticular pattern in lung; pulmonary function tests revealed impairment; lung biopsy tissue revealed iron oxide and silica.
Mignolet 1950	Oxyfuel gas and arc welding, and oxyacetylene cutting	No exposure data.	Medical histories evaluated on 216 welders: 61% arc welders, 41% oxyacetylene cutters and 18% oxyfuel gas welders had abnormal radiographs with localized or generalized sclerosis.
<u>Bronchitis/pulmonary function:</u>			
Hunnicutt et al. 1964	Arc welding	Chronic exposure of shipyard welders. No exposure data.	Decrement (p=0.01) in FEV_1, MEFR, and MMF volumes for welders relative to unexposed controls. Welders who smoked had twice the incidence of abnormal pulmonary function than controls who smoked.

(Continued)

Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Bronchitis/pulmonary function:</u>			
Fogh et al. 1969	Arc welding	Chronic exposure of shipyard welders and some engine/boiler welders. No exposure data.	Increased symptoms of chronic bronchitis was observed for smokers in both welders and controls. Impairment of pulmonary function was found to be increased in welders who smoked from nonsmoking welders. This difference was not observed between smokers and nonsmokers in the controls.
Barhad et al. 1975	Arc welding, some oxy-acetylene torch and shielded welding	Chronic exposure of shipyard welders. Concentrations of welding fume: 6-36 mg/m^3 in welders' breathing zone and 48-92 mg/m^3 in confined spaces.	Dyspnea and wheezing ($p<0.001$) and paroxysmal dyspnea ($p<0.005$) increased in welders compared to controls.
Akbarkhanzadeh 1980	Shielded metal arc welding	Chronic exposure of shipyard welders. No exposure data.	Prevalence of chronic bronchitis increased with age, greater in welders than controls and greater among smokers.
Kujawska 1968	Arc welding	60 welders had at least 10 years of exposure, of which half had siderosis. No exposure data.	Welders with siderotic changes had lower VC and FEV_1 values when compared to other welders or controls. Chronic bronchitis more prevalent ($p<0.05$) in welders than nonexposed controls. Similar distribution of smokers and nonsmokers.

(Continued)

Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Bronchitis/pulmonary function:</u>			
Antti-Poika et al. 1977	Electric arc welding	157 welders employed in engineering shops had at least 3 years of exposure. Concentrations of total welding fume: 1-9 mg/m^3, 8-hr TWA.	Chronic bronchitis more prevalent ($p<0.01$) among welders than nonexposed controls.
Doig and Challen 1964; Glass et al. 1971	Arc welding	Acute exposure of welders working near degreasing tanks that contained trichloroethylene. Probable decomposition and formation of phosgene.	Respiratory distress, cough, chest constriction, breathlessness, arterial hypoxia, and impaired carbon monoxide transfer.
Sjogren and Ulfvarson 1985	Gas metal or tungsten arc welding (Group 1). Arc welding (Groups 2 and 3).	Welders placed into three exposure/job groups: Group 1: Gas metal arc welding on aluminum. 50% of ozone exposures exceeded 0.1 ppm. Group 2: Welded with covered electrodes on stainless steel. 80% of chromium(VI) exposures exceeded 20 μg/m^3. Group 3: Welded on railroad tracks. Nitrogen oxides were below 5 ppm for all 3 groups.	Respiratory symptoms more prevalent for welders in Group 1 when compared to controls, significant ($p=0.03$) with increasing exposure to ozone. Chronic bronchitis higher in all three groups when compared to controls. No differences in pulmonary function. Increasing respiratory symptoms in Groups 2 and 3 with increasing chromium exposures but no relationship with increasing total fume concentrations.

(Continued)

Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Bronchitis/pulmonary function:</u>			
Keimig et al. 1983	Gas metal arc welding and flux core welding	The study group was made up of 91 welders (46 nonsmokers, 45 smokers) and 80 controls (35 nonsmokers, 45 smokers). Welding of mild steel: breathing zone air samples indicated iron oxide concentrations of 1.3–8.5 mg/m^3. No detectable amounts of chromium, copper, fluoride and lead in any samples.	Welders and controls who smoked had a higher frequency of respiratory symptoms than nonsmokers. Nonsmoking welders and smoking welders, compared to respective controls, did not have significantly decreased FVC or FEV_1. Welders who did not smoke had a reported increase ($p<0.05$) in phlegm and episodes of cough and phlegm when compared to nonsmoking controls.
Oleru and Ademiluyi 1987	Shielded and manual metal arc welding	Study group made up of 67 (36.8%) of a total 182 men employed in an industry that made window and door frames from medium and high-alloy steel and aluminum. No exposure data. Authors hypothesized that airborne dust concentrations probably exceeded 5 mg/m^3 based on the amount of settled dust.	Seven cases of restrictive lung impairment were observed: 3 paint dippers, 2 aluminum workers and 2 welders. Welders given spirometric lung function tests demonstrated statistically significant ($p<0.05$) decrements in all parameters measured when evaluated over a 40-hr work week. Peak flow measurements were reduced ($p<0.05$) for welders when measured at the end of the 8-hr work shift.

Table IV-3.—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR[a] (95% CI[b] or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies:</u>								
Sjogren, 1980[c]	Welders who had stainless steel welding as their main task for at least 5 years between the period 1950 and 1965 and were followed to 1977. No exposure to asbestos and welded with covered electrodes most of the time (207 out of 234 welders).	234 welders (all males) 3,735 person-years; 100% followup of subjects.	Controls: 5-year study adjusted for cause, gender, age, and year. Specific national death rates of Sweden.	3	0.7		4.4 ($p<0.03$)	No
				3	0.7		4.4 ($p<0.05$)	Yes[d]

(Continued)

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[a] Standard mortality ratio.
[b] Confidence interval.
[c] Primary exposure to chromium and nickel. Pulmonary tumors observed in 3 welders: Welder A used covered electrodes on stainless steel from mid-40's; died in 1957. Welder B used covered electrodes on stainless steel from mid-40's until 1957; died in 1977 of a non-differentiated pulmonary tumor. Welder C gas-shielded from 1940 until 1969; died in 1977 of a highly differentiated adenocarcinoma. Welders A & B smoked; Welder C stopped smoking 20 years before death.
[d] It was estimated that 10% more welders smoked than did members of the control group (Swedish male population).

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
Cohort Mortality Studies:								
Sjogren, et al., 1987[e]	Follow-up study reported by Sjogren (1980). Analysis and comparison of railway track welders exposed to low concentrations of chromium (<10 mg/m^3). Both cohorts worked for at least 5 years between 1950 and 1965 and were followed until December 1984. No reported exposure to asbestos.	Follow-up of 234 welders (Sjogren 1980). 208 railway track welders. All males in both cohorts.	Controls: 5-year age categories by cause, gender, age, and calendar-year. Specific national death rates.	Cohort of 234				
				5	2	249 (80–581)		No
				Cohort of 208				
				1	3	33 (0–184)		No
							7.0[f] (1.32–37.3)	

(Continued)

[e] Follow-up study of 234 stainless steel welders (5324 person-years) exposed to high concentrations of chromium (Sjorgen 1980). Analysis of 208 welders (5273 person-years) exposed to low concentrations of chromium.

[f] Comparison of welders exposed to high concentrations of chromium with welders exposed to low concentrations to determine risk of developing lung cancer.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Becker et al., 1985[g]	Arc welders from 25 factories (e.g., sanitary installations, power plants and boilers) who started between 1950 and 1978 and followed to 1983.	1,224 welders (all males); 23,492 person-years. 96% follow-up of subjects.	(a) 1,694 turners (internal control) who were not exposed to nickel or chromium.	(a) Welders: 6	10		1.7 (0.7–4.0)	Yes
			(b) Total population of Germany (external control).	(b) Welders: 6	6.3	95.5 (p<0.05)		Yes
				Turners: 10	14.5	69.2 (p<0.05)		Yes

(Continued)

[g] Upward trend in the SMR (compared with German population) for welders when analyzed by time since first exposure; reached statistical significance for malignant neoplasms in last time interval (≥30 years). Characteristic of a healthy worker effect; no upward trend seen for turners. Welders used covered chromium-nickel alloyed electrodes and gas shielded with covered chromium-nickel alloyed wire.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
Cohort Mortality Studies:								
Beaumont and Weiss 1981	Welders from the State of Washington employed in various industries, primarily shipbuilding, field construction, and metal fabrication shops.	3,247 welders who were union members for a minimum of 3 years including at least 1 day between 1950 and 1973 and followed to 1977 (43,670 person-years).	(a) U.S. death rates for white males used.	(a) 50	37.95	132 (p=0.06)		No[h]
					22.38	174[i] (p<0.001)		No[h]
			(b) 5,432 nonwelders (internal control).	(b) 39[j]			1.28 (0.89–1.84)	No[h]

(Continued)

[h] Internal control group (nonwelders) used to account for smoking.
[i] ≥20 years since first exposure.
[j] Excess risk of lung cancer examined by age at risk, calendar time, age started work, year started work, duration of exposure, and latency. Both age at risk and calendar time exhibited a positive trend. Duration of exposure and latency were strongly associated with lung cancer. Attributable risk: 23.1 lung cancers/100,000 welders per year (11.2–57.5).

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Steenland et al., 1986[l]	Reanalysis of the Beaumont and Weiss 1981 study cohort. Cox and logistic regression analysis performed to compare lung cancer risk.	3,247 welders from the State of Washington employed at least 1 day between 1950-1973 and followed to 1977.	5,432 non-welders (e.g., pipefitters, riggers) that belonged to the same union.				1.52[k] (p=0.03) 1.29[m] (p=0.03) 1.15[n]	

(Continued)

[k] Logistic analysis indicating a statistically significant interaction observed between welding and year-first-employed for lung cancer.
[l] Analysis of welders for lung cancer risk using internal non-exposed comparison group and two types of regression analysis. A total of 137 lung cancer deaths (50 welders, 87 controls).
[m] Logistic analysis indicating a statistically significant interaction between cumulative exposure of welders and lung cancer.
[n] Cox regression analysis indicating elevated lung cancer risk among welders when analyzed by cumulative exposure.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
Cohort Mortality Studies:								
Newhouse et al., 1985[p]	Welders, caulkers, burners, platers, and electricians who were employed at shipyards in England between 1940 and 1968 and who were followed through 1982. Occupations selected on potential exposure to welding fumes.	Welders (W): 1,027. Caulkers (C): 235. Platers (P): 557. Electricians (E): 1,670. (99.5% followup of subjects)	Population rates for males in the Newcastle area of England.	W: 26	22.9	113 (80–157)[o]		No[o]
				C: 12	5.2	232 (133–374)[o]		No[o]
				P: 12	12.1	100 (57–161)[o]		No[o]
				E: 35	33.6	104 (75–133)[o]		No[o]

(Continued)

[o] Note: 90% confidence limits on SMR's. No information on smoking habits.
[p] 13 deaths due to mesothelial tumors: 9 among electricians, 2 among platers, and 1 each among welders and caulkers (excluded from lung cancer cases). When welders and caulkers (groups with the highest potential to welding fume) were combined, lung cancer deaths were statistically significant (no SMR given). Deaths due to pneumonia were elevated for welders and caulkers with SMR's of 184 (100–314) and 165 (30–525), respectively.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
Cohort Mortality Studies:								
Polednak, 1981[q]	Welders at 3 nuclear facilities at Oak Ridge, Tenn., who were hired between 1943 and 1974 and followed through 1974. Subgroup of 536 welders exposed mostly to nickel oxides and fluoride. Subgroup of 523 welders performed only tungsten inert gas (90%) and shielded metal arc (10%) welding.	Total of 1,059 white male welders (23,674 person-years); 92% follow-up of subjects.	U.S. white males.	All welders				
				17	11.37	150 (87-240)		No
				Welders exposed to nickel oxides				
				7	5.65	124 (50-255)		No
				Other subgroup of welders				
				10	5.71	175 (84-322)		No

(Continued)

[q] The subgroup of welders exposed to nickel oxides between 1975 and 1977 had a TWA concentration of $0.57 mg/m^3$ nickel. The other subgroup of welders monitored between 1973 and 1977 had 3 samples that exceeded $0.1 mg/m^3$ nickel and 21 samples that were below the limit of detection. Of 10 samples collected for chromium in this subgroup, all but one ($2.22 mg/m^3$) were below $1.0 mg/m^3$. Most TWA's for iron oxide in both subgroups were below $5 mg/m^3$. Welders who worked 50 weeks or more with nickel-containing electrodes showed 5 lung cancer cases compared with 2.66 expected.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	No. of cases Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Dunn and Weir, 1968	Multiple occupations followed prospectively (deaths between 1954 and 1962). Follow-up of study group until death, 70th birthday, or Dec. 31, 1962 (study completion).	Total study population of 68,153 men from a number of unions in California; 482,658 total person-years. Welders: 81,389 person-years. Person-years determined from ages 35-69.	Internal comparison.	49	46.5[t]	Not reported	1.05 NS[s]	Yes

(Continued)

[r] Expected number of deaths calculated with rates specific for age and amount of smoking observed for all occupational groups combined. Smoking histories gathered through a questionnaire. Only 1% of population had died.
[s] Not statistically significant.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Puntoni et al., 1979[t]	Shipyard workers analyzed by 19 occupational groups (including electric and gas welders). All workers who were employed or who had retired as of 1960, 1970, and 1975 and all who were dismissed or retired during 1960-75. Followed for mortality until 1975.	Electric welders: 2,106 person-years Gas welders: 1,723 person-years.	(a) Male staff of St. Martino Hospital, Genoa, Italy.	(a) Gas welders: 4	 1.89		 2.12 NS	 No
				Electric welders: 3	 1.18		 2.54 NS	 No
			(b) General male population of Genoa, Italy (same study time-period.	(b) Gas welders: 4	 3.20		 1.25 NS	 No
				Electric welders: 3	 1.88		 1.60 NS	 No

(Continued)

[t] No smoking or age adjustment; poor cohort definition.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)[u]	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies (Malignant neoplasms)</u>:								
Ott et al., 1976	All employees at a chemical facility (except those exposed to arsenicals or asbestos) as of March 1954 and followed until 1973. Analysis performed on 15 job categories (including welders/leadburners)	Total study group: 8,171. Subcohort A hired before 1950: 5,994. Subcohort B hired between January 1950 and March 1954: 2,177. Total welders: 180.	U.S. white males.	Subcohort A: 256	259.2	99		No
				Subcohort B: 28	35.9	78		No
				Welders: 12	7.4	162[v]		No

(Continued)

[u] SMR's reported for malignant neoplasms.
[v] Note: 2 of the 12 malignant neoplasms for welders were at respiratory sites. No CI or p values given, but reported as not being statistically significant. No exposure data.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cross-sectional Mortality Studies</u>:								
Menck and Henderson 1976[w]	2,161 death certificates (1968-70) of white males aged 20-64 (Los Angeles Co.) and pooled with all 1,777 incident cases of lung cancer for white males, same age group, reported to the Los Angeles Co. Cancer Surveillance Program for 1972-73.	Welders: 21 deaths and 27 incident cases of lung cancer.	Estimated from 1970 census, Los Angeles County occupational data. Each occupation assumed to have same probability of lung cancer as entire population; estimated 15,300 welders in L.A. county.	48 (mortality and incident cases)	Not reported		1.37 ($p<0.05$)	No

(Continued)

[w] Age adjustment was not complete. No exposure data. Analysis performed by job category and industry.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	PMR[x] (95% CI or p value)[u]	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cross-sectional Mortality Studies</u>:								
HMSO 1978	English and Welsh welders' and burners' deaths recorded during 1968-69.	128,000 welders; approx. 256,000 person-years. Job-titles: Gas, electric welders; cutters, brazers.	Age adjusted general population.	246	192	151 (p<0.01)		No
						116[y] (p<0.01)		Yes

(Continued)

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[x] Proportional mortality ratio.
[y] SMR adjusted for the welder's incidence of smoking, which was 22% higher than that expected in the general population.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases		PMR (95% CI or p value)[u]	Odds ratio (95% CI or p value)	Controlled for smoking
				Observed	Expected			
<u>Proportional Mortality Study</u>:								
Milham, 1983	Occupation and cause of death on 429,926 Washington State white males for 1950-79.	Welders and flame cutters. Total deaths: 2,124	All Washington State deaths.	153	114	126[z] (p<0.01) 135[aa] (p<0.01)		No No

[z] Respiratory system cancers.
[aa] Tracheal, bronchial, lung cancer. No exposure data.

Table IV-4.—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study[a]	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI[b])	Controlled for smoking
Blot et al., 1978	Investigated high rate of lung cancer among white male residents of 11 county coastal areas in Georgia. Cases identified from one large hospital since 1970, 3 other hospitals during 1975-76, and ascertainment of death certificates for lung cancer within the counties.	458 cases of primary lung cancer identified of which 11 had worked as welders.	553 controls from hospital admissions and from death certificates for diagnoses other than lung or bladder cancer or chronic lung disease. Two controls for each case matched closely by sex, race, age, residence, and current vital status.	11 welders	20 controls	1.6[c] (1.1-2.3) (p=0.006) 0.7[d]	Yes

(Continued)

[a] Questionnaire given to next of kin to determine place, type, and length of employment for any job held more than 6 months. Risk for lung cancer increased with smoking and working in a shipyard. Interviews completed for 89% of lung cancer cases and 87% of the controls. Excess risk seen for other shipyard workers but not welders or riggers.
[b] Confidence interval.
[c] Those ever employed in a shipyard; number of cases and controls not given.
[d] Crude relative risk for welders and riggers.

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Gottlieb, 1980[e]	Assessment of death certificates (1960-75) for Louisiana to determine deaths from lung cancer primarily among people employed in petroleum mining and refining industries.	8 cases of lung cancer among welders employed in the petroleum industry. 200 cases of lung cancer identified for all occupations within the petroleum industry.	170 controls employed in the petroleum industry.	All workers in petroleum industry			
				200 lung cancers	170 controls	1.19 (1.05-1.35)	No
				Welders in petroleum industry			
				All welders:			
				8 welders	2 controls	1.54 (p<0.09)	No
				Welders <60 yrs. of age at death:			
				5 welders	1 control	1.89 (0.48-7.37)	No
				Welders >60 yrs. of age at death:			
				3 welders	1 control	0.93 (0.25-3.46)	No

(Continued)

[e] Excess of lung cancer mortality among welders in the petroleum industry was not observed across all industry categories. Mean age of death for these cases was several years older than that for controls.

Table IV-4 (Continued).--Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Gerin et al., 1984[f]	Case-referent study of 12 cancer sites and possible occupational exposures. Male population aged 35-70 years in Montreal, Canada from Oct. 1979 to June 1982. Determined cancer risk based on case-ascertainment in 17 hospitals.	32 welders: 21 with nickel exposure; 11 without nickel exposure. 58 nonwelders with nickel exposure.	General populations elected from electoral rolls with age-distribution comparable.	All welders			
				32	12	2.4 (1.0-5.4)	Yes
				Welders with nickel exposure			
				21	10	3.3 (1.2-9.2)	Yes
				Welders without nickel exposure			
				11	2	1.2 (0.1-9.4)	Yes
				Nonwelders with nickel exposure			
				58	19	2.9 (1.3-5.7)	Yes

(Continued)

[f] Occupational histories evaluated and potential exposures assigned to physical and chemical agents. Ethnic group, socioeconomic group, and smoking habits ascertained. Potential exposure to nickel and compounds was assigned to 79 out of 1,487 cases. Potential exposure to chromium and nickel was highly correlated--78 out of the 79 cases also had chromium exposure. Risk highest among welders exposed to nickel (mainly among stainless-steel welders).

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Breslow et al., 1954[g]	Determined occupational history and tobacco use of lung cancer patients. 518 patients (493 males) observed during 1949-52 in 11 California hospitals. Analyzed by occupation (minimum of 5 years employed in a particular job).	Ten cases that were classified as being employed as welders and flame cutters. Four cases of sheet metal workers who did welding.	Patients admitted to the same hospital as the cases, matched for age (within 5 years), sex, and race. Patients who did not have cancer or chest disease.	Welders			
				10	1		Yes
				Welders/sheet metal workers			
				14	2	1.56[h]	Yes

(Continued)

[g] Questionnaire given to cases and controls to determine occupations, potential exposure to toxic materials, and smoking habits. 93% of the lung cancer patients and 76% of the controls smoked. All 14 welders/sheet metal workers with lung cancer smoked.

[h] By applying the proportion of welders/sheet metal workers among total cases and controls in each smoking category, an expected number of welder cases was estimated to be 9, giving an observed/expected ratio of 14/9, or 1.56.

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Olsen et al. 1984[l]	Association between laryngeal cancer and exposure to welding fumes. Patients less than 75 years of age with cancer of the larynx selected in Denmark during March 1980 to March 1982.	271 laryngeal cancer patients of which 42 were exposed to welding fumes. Of the 42, 12 were exposed to fumes from stainless steel.	Controls (971) matched to cases according to residence, sex, and possible date of birth (from the municipal person register in which the case was listed).	Total larynx cancer; 271(12[i])	971(30[j])	1.3	Yes (0.7–2.7)[k]
				Glottic cancer: 176(8[i])	971(30[j])	1.3	Yes (0.6–3.1)[k]
				Supraglottic cancer: 79(2[i])	971(30[j])	0.7 (0.2–3.2)[k]	Yes
				Subglottic cancer: 11(2[i])	971(30[j])	6.7 (1.0–33.3)[k]	Yes
				Unclassifiable site of origin: 5(0[i])	971(30[j])	—	Yes

(Continued)

[i] Number exposed to stainless steel welding fume.
[j] The 42 of the 271 cases exposed to welding fumes had a statistically significant OR of 6.3 (95% C.I.=1.8–21.6) for the subglottic area of the larynx.
[k] Adjusted relative risks (age, average alcohol and tobacco consumption) and 95% confidence intervals.
[l] Data collected from questionnaires on occupation, possible exposures, use of tobacco and alcohol. Medical records also used for cases.

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study[m]	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Schoenberg et al. 1987	Investigate lung cancer risk among white males from six geographical areas of New Jersey. Risk estimates determined by job title or industry job title category.	763 white males with histologically confirmed primary cancer of the trachea, bronchus, and lung.	900 white males from same geographical area in New Jersey.	All Welders:[n]			
				33	18	3.8 (1.8 - 7.8)	Yes
				Welders with no asbestos exposure:[n]			
				17	11	2.5 (1.1 - 5.5)	Yes

[m] Personal interviews of all cases and controls, or next of kin, were conducted to collect demographic data, personal and environmental risk factors, smoking history, and diet. Industry and job title information coded with 1970 census index system; 42 job title categories and 34 industry job title categories were chosen for analysis.

[n] Welders were identified as an industry job title category within shipbuilding workers.

capable of causing this disease, exposure to zinc oxide has been the most common cause in welders (Drinker 1922; Drinker et al. 1927). The clinical signs and symptoms of metal fume fever resemble those of an upper respiratory infection such as influenza, acute bronchitis, or pneumonia, or an upper gastrointestinal infection (Papp 1968). Chills, shivering, trembling, nausea, and vomiting may occur (Rohrs 1957). The attack usually lasts 6 to 12 hr and in some instances up to 24 hr. Weakness and mild prostration follow but recovery is usually complete. With repeated exposure, an increased resistance develops but this apparent tolerance is lost within a short time (e.g., during a weekend). The attacks tend to be more frequent and prevalent on Mondays (Drinker 1922; AGA 1978).

Although other reports exist, the studies of Ross [1974] and Johnson and Kilburn [1983] are typical examples of symptomatic effects reported in welders. Ross [1974] reported a case of metal fume fever in a shielded metal arc welder exposed to mixed fumes. Although the covered electrode contained primarily nickel, the fume contained iron, calcium, fluoride, manganese, silica, titanium, aluminum, copper, nickel, and traces of other metals. The welder experienced a severe headache and felt cold and shivery. The next day he experienced tightness of the chest, profuse sweating, and unusual thirst. Chest examination revealed wheezing. His temperature varied between 99.5° and 101.5°F (37.5° and 38.6°C). On the basis of occupational history and clinical findings, he was diagnosed as having metal fume fever complicated by pneumonia and was removed from further exposure. Two months later he was completely recovered and returned to work.

Johnson and Kilburn [1983] described the illness of a 30-year-old male Caucasian who had welded for 9 years and who became ill following torch brazing. Several filler metals that contained zinc, cadmium, copper, or mild steel were used in the process. To assist in the diagnosis, the welder was asked to braze with a silver-based filler metal containing 24% cadmium. Shortly after he started to weld, he complained of eye irritation and headache. The worker's blood leukocyte count increased 6 hours after exposure and peaked at 13 hours (increase not reported). Nine hours after onset of exposure, he developed muscular pain, chills, feverish feelings, headache, backache, chest tightness, malaise, and shortness of breath. Ten hours later, his body temperature rose and peaked at 100°F (37.7°C) for about 13 hours. A chest radiograph taken 13 hours after exposure indicated the presence of nodular densities that were not apparent in radiographs taken before exposure or after recovery (time of examination not given). As a result of these observed effects, the welder discontinued brazing with silver-based filler metals; a 6-month follow-up examination revealed no further subjective symptoms. The authors concluded that cadmium, which was present in the silver-based filler metal the welder was using, was the causative agent in this case of metal fume fever.

(b) Pneumonitis

Pneumonitis and pulmonary edema have been frequently reported among welders who use various types of welding processes (e.g., gas and shielded metal arc, silver brazing, and oxyacetylene) in which exposures to the following have been identified: nitrogen dioxide (Maddock 1970; Mangold and Beckett 1971), ozone (Molos and Collins 1957; Kleinfeld et al. 1957; Challen et al. 1958), cadmium fumes (Patwardhan and Finckh 1976; Blejer and Caplan 1969; Townshend 1968), chromium and nickel fumes (Jindrichova 1976), and aluminum and iron fumes (Herbert et al. 1982).

(i) Exposure to Metal Fumes

Cases of acute cadmium fume pneumonitis and death have been reported among welders who were exposed to cadmium fumes by either brazing with silver-cadmium alloy or cutting or welding cadmium-coated metal in poorly ventilated areas (Christensen and Olson 1957; Beton et al. 1966; Patwardhan and Finckh 1976). Beton et al. [1966] reported the death of a welder who was cutting cadmium-plated bolts with an oxyacetylene torch in a confined space. Although exposure measurements for cadmium fumes were not taken, the authors estimated that exposure to cadmium oxide may have averaged 8.6 mg/m^3 based on the amount of cadmium oxide found in the welder's lungs during a postmortem examination.

Patwardhan and Finckh [1976] reported on another fatality that occurred in a 38-year-old man who was exposed to cadmium fumes while welding handles onto cadmium-plated drums. No respiratory protection or local exhaust ventilation was used. He developed respiratory distress, fever, and chills the first night after exposure. On the third day of his illness, he was admitted to the hospital, where chest X-rays revealed heart enlargement and pulmonary edema. He died of cardiac arrest approximately 3-1/2 days after exposure to cadmium fumes. Postmortem examination revealed lung changes consistent with pulmonary edema and diffuse congestion of alveolar capillaries. The liver contained 0.23 mg cadmium and the lungs contained 0.15 mg cadmium per 100 g of wet tissue.

Townshend [1968] reported on a 4-year evaluation of a 51-year-old welder who had suffered from acute pneumonitis following exposure to fumes from the welding of a silver-cadmium alloy. On the day of the incident, the welder had been using an argon arc to weld plates composed of an alloy of 91% silver and 9% cadmium. The night after exposure, he developed a burning pain in the chest, dyspnea, and dry cough and was hospitalized. The first chest radiograph was taken 23 days after the incident and showed extensive bilateral shadows, suggesting severe pulmonary edema. Eight weeks after the incident, extensive patchy shadowing was still evident. For 6 months after the exposure, lung function tests showed a progressive improvement in the forced vital capacity (FVC) to just under 80% of the predicted value, after which there was no further improvement. After 4 years, the chest X-ray showed faint nodulation. No information on smoking habits or exposure concentrations were reported.

Jindrichova [1976] and Herbert et al. [1982] reported on pneumonitis that occurred in welders exposed to fumes composed of various types of metals. Jindrichova [1976] used nose, throat, and neurologic examinations and chromium determinations from the urine to study 31 welders who welded with shielded metal arc on metals containing chromium. These welders were compared with 26 workers who were not exposed to welding fumes or chromium. All welders were divided into three groups. Group 1 consisted of 9 welders who spent about 13% of their time working with electrodes containing chromium. Group 2 consisted of 11 welders who spent half of their time using electrodes containing either 18% chromium and 9% nickel, or 23% chromium and 19% nickel. Group 3 consisted of 11 welders who used electrodes containing 19% chromium and 9% nickel for 70% of their welding time. Welders in Group 3 were exposed to a concentration of 0.75 mg/m^3 of chromium (0.62 mg/m^3 soluble chromium[VI]) oxide measured inside a container (1.1 x 3.3 m) that had no local exhaust. The same work performed with local exhaust ventilation produced a chromium concentration of 0.16 mg/m^3 (0.12 mg/m^3 soluble chromium(VI) oxide. No exposure data were given for Groups 1 and 2, but chromium exposures for Group 2 were reported to be the same as for the control group. Group 1 had no evidence of chronic bronchitis, but one welder had a chronic atrophic rhinitis with acute nosebleeds. In Group 2, one welder with 25 years of experience had pulmonary fibrosis associated with siderosis. In Group 3, all of the welders had coughs and respiratory problems. Seven of the 11 welders smoked. In Group 3, erosion of the nasal septum was found in 35% of the welders, atrophic rhinitis in 54%, pharyngitis in 45%, chronic laryngitis in 11%, and bronchitis in 72%. The findings of nasal erosion in Group 3 were consistent with chromate-induced lesions. Concentrations of chromium in urine (122-128 μg/liter of urine) for welders in Group 3 were significantly higher than either the control group or Groups 1 and 2 (concentrations not reported). Although these differences were reported to be statistically significant, no statistical methods were discussed.

Herbert et al. [1982] described chronic interstitial pneumonitis in a 35-year-old male electric arc welder who had been employed as a welder for 16 years. A biopsy of the lung revealed unspecified quantities of iron and aluminum particles and occasional asbestos bodies. Chest X-rays revealed bilateral basal infiltrates with a more discrete opacity on one side. Lung function tests showed diminished forced expiratory volume (FEV), FVC, and total lung capacity. The welder had smoked for a short period but had not smoked for the past 20 years. No exposure data were reported.

(ii) Exposure to Gases

Cases of pneumonitis and acute pulmonary edema in welders have been attributed to the inhalation of nitrogen dioxide [Maddock 1970; Mangold and Beckett 1971] and ozone [Molos and Collins 1957; Kleinfeld et al. 1957; Challen et al. 1958]. Mangold and Beckett [1971] reported on two silver brazers who were assembling a cupronickel firemain in the overhead of a 2- by 3- by 4.6-m storage compartment aboard a ship. The workers used a "silver solder" containing 80% copper, 15% silver, and 5% flux. The flux contained 27% potassium fluoride and 72% potassium borate. No local exhaust ventilation was used. Respiratory irritation forced the men to stop working after 30 min, and both were hospitalized 6 to 8 hr later with acute pulmonary edema and lung damage. One worker returned to work in a few days, whereas the other retired because of respiratory impairment. Reconstruction of the event indicated that no cadmium-bearing solders were used but that nitrogen dioxide concentrations increased from 0.38 to 122 ppm in 30 min.

Maddock [1970] reported a fatality resulting from pulmonary edema in a boilermaker who used two oxyacetylene torches with multiple jets to repair a rudder post in an enclosed compartment. He worked for several hours without complaint but developed a cough that evening. The worker was admitted to a hospital and died the following day. Death was attributed to pulmonary edema resulting from nitrogen dioxide poisoning. Reconstruction of the event revealed that a blower had dispersed the fumes throughout the compartment instead of ventilating it. The nitrogen dioxide concentration was found to exceed 20 ppm within 3 min of lighting the torches. The boilermaker had been exposed to nitrogen dioxide at an estimated concentration greater than 100 ppm.

Case reports described by Molos and Collins [1957], Kleinfeld et al. [1957], and Challen et al. [1958] document how pneumonitis can occur from the inhalation of ozone during argon-oxygen shielded and gas metal arc welding. Molos and Collins [1957] described respiratory irritation in a welder who performed argon-oxygen shielded gas metal arc welding on mild steel tanks using a mixture of 98% argon and 2% oxygen. From time to time, the welder and other workers complained of respiratory and eye irritation. Occasionally, the irritation became so severe that welding had to be discontinued. The welder continued to complain of discomfort and described symptoms of chest cramps, fatigue, headaches, impaired appetite, shortness of breath, difficulty in sleeping, and a persistent cough with occasional blood-tinged sputum. The mean ozone concentration was 2.6 ppm during welding activities. Substitution of pure argon or carbon dioxide eliminated worker complaints, but the resulting welds proved to be unacceptable and gas shielded metal arc welding was discontinued.

Pneumonitis was also reported by Kleinfeld et al. [1957] in eight welders who used gas metal and gas tungsten arc welding machines that were located in a corner of a room measuring 60 by 27 by 3 m. No supplementary ventilation was provided. The work was performed on various metal parts that contained nickel. The ozone concentration in the breathing zones of the welders was 9.2 ppm; nickel carbonyl and oxides of nitrogen were not detected. A trichloroethylene degreaser was located about 15 m from the welding area, but air measurements were negative for phosgene, a photodecomposition product of trichloroethylene. One welder was admitted to a hospital with pulmonary edema an hour after leaving work. Chest X-rays revealed diffuse peribronchial infiltration consistent with multilobular pneumonia. He remained in critical condition for 2 days with persistent pulmonary congestion, and he recovered after 2 weeks. Two of the eight welders developed dyspnea, and X-ray examination revealed scattered radiographic densities over both lung fields. Both workers were hospitalized and recovered within 9 days. Four of the remaining five welders complained of severe headaches and throat irritation.

Challen et al. [1958] also described symptoms of upper respiratory tract irritation in 11 of 14 welders who were exposed to ozone at concentrations of 0.8 to 1.7 ppm while performing gas tungsten arc welding on aluminum. These symptoms ceased when the concentrations of ozone were reduced to approximately 0.2 ppm; no mention of aluminum concentration was made.

(c) Pneumoconiosis, Including Siderosis

In 1936, clinical, radiographic, and pathologic changes in welders' lungs were first described by Doig and McLaughlin [1936]. They reported nodulations in the lungs of eight electric arc welders employed for 7 to 12 years. Similar findings were reported 2 years later [Enzer and Sander 1938] on a group of 26 electric welders who used bare metal electrodes and were exposed to iron oxide. Microscopic examination of a lung tissue biopsy from 5 of the 26 welders revealed no parenchymatous changes or fibrosis, but it did reveal a large quantity of iron deposited in the bronchi, the lymphatic vessels, and the alveolar septa--a condition that is characteristic of siderosis.

Numerous other reports described similar findings of asymptomatic, benign, and radiologically detectable lung changes attributed to the deposition of iron oxide fume particles in the lung (Britton and Walsh 1940; Sander 1944; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950). Although no exposure conditions were reported in these studies, the respiratory effects noted were in electric welders who were employed before 1950, when bare metal electrodes were primarily used.

To a large extent, bare metal electrodes have been replaced by covered electrodes. In addition to iron, covered electrodes often contain silicon, silicates, fluorides, titanium, manganese, copper, and other metals. With the increased use of covered electrodes, there have also been increases in reports of fibrosis, respiratory impairment, and active lesions at the site of accumulation of iron particles in the lungs. The following reports are representative of such observations in welders exposed to fumes of mixed composition.

Dreesen et al. [1947] reported an investigation on the health status of arc welders in steel ship construction from seven shipyards. Medical examinations were made of 4,650 workers, 70% of whom were welders. Less than 6% of the welders had more than 3 years of shipyard experience. The study population was divided into three groups: welders (Group 1); persons who did not have a clearly defined welding or nonwelding work history (Group 2); and nonwelders, including electricians, machinists, and sheet metal workers who did not have an exposure to welding fumes (Group 3). Arc welder's siderosis was diagnosed in 61 (3%) of the welders in Group 1 and in 10 (3%) of the persons in Group 2. All welders in Group 1 had a lower mean systolic blood pressure that was unrelated to age and no appreciable difference in the hematocrit and erythrocyte sedimentation rate. Approximately 25% of the welders had slag burns or scars. Welders (Group 1) had approximately the same visual acuity as those persons in Groups 2 and 3 when the data were adjusted for age. Conjunctival irritation was slightly more prevalent among welders when compared to the other two groups. Greater incidences of nasal congestion, pharyngitis, and upper respiratory symptoms were reported in welders from Group 1, with tobacco-using welders in this group showing even greater incidences; however, these differences were not reported to be statistically different when compared to those persons in Groups 2 and 3. In the chest X-rays of welders, a slight increase in lung field markings was observed as length of welding experience increased.

A total of 1,761 welding fume samples were collected and analyzed for iron and total fume. Zinc was evaluated in 278 and lead in 25 of these samples. Iron fume concentrations in excess of 20 mg/m^3 (>30 mg/m^3 expressed as ferric oxide) were found in all welding locations. The highest average iron and total fume concentrations were found in confined spaces where no ventilation was installed. Zinc concentrations in excess of 12 mg/m^3 (>15 mg/m^3 expressed as zinc oxide) were reported. No exposure data were given for total fume or lead.

To determine the frequency of siderosis, Mignolet [1950] examined and assessed the medical histories of 216 workers who were classified into the following groups: 32 oxyfuel gas welders, 99 oxyacetylene cutters, and 85 arc welders. These groups were compared with 100 workers selected from other occupations; the types of occupations and their potential for exposure to welding fumes were not stated. The number of abnormal X-rays was much higher among arc welders (61%) than among the oxyacetylene cutters (41%), the oxyfuel gas welders (18%), and the comparison group (17%). The changes included pleural adhesions, distinct diffuse sclerosis, and enlarged hilar shadows. The changes were attributed to the inhalation of iron oxide and other metals from the coverings of electrodes. In all cases, the siderosis was a localized sclerosis, not granular. Based on these findings, the author concluded that arc welding was more hazardous than oxyacetylene cutting and oxyfuel gas welding.

Marchand et al. [1964] and Attfield and Ross [1978] have likewise reported on the radiological examination of arc welders. Marchand et al. [1964] reported on the incidence of pneumopathy in 402 arc welders. Of this total, 192 had worked for 5 to 10 years, 137 had worked for 11 to 15 years, 54 had worked for 16 to 25 years, and 19 had worked for more than 25 years. Pneumoconiosis was radiologically demonstrable in 25 (7%) of the 402 welders, with 13 of the 25 cases found in the group that had worked for 11 to 15 years (the remaining 12 cases not identified). Of the 25 cases of pneumoconiosis, 7 (6 of which were in the group exposed for 11 to 15 years) were classified as siderosis.

Attfield and Ross [1978] studied radiological abnormalities in 661 electric arc welders who were engaged in many types of arc welding, including gas metal arc and gas tungsten arc processes. No exposure data were given, but 264 (40%) of the welders said they had worked near locations where asbestos was being used. Results from radiological examination of the welders indicated that 53 (8%) of them had small rounded lung opacities. Of those 53 welders, 41 (78%) had opacities that measured from 1.5 to 3 mm in diameter. One film showed lung opacities with diameters of 3 to 10 mm, while the balance of the films revealed opacities that ranged from just visible up to 1.5 mm in diameter.

The clinical findings reported by Meyer et al. [1967] of a 55-year-old arc welder who had been employed at a shipyard for 24 years were consistent with the findings previously reported by Dreesen et al. [1947] on other shipyard welders. The welder had worn a welding helmet only intermittently and frequently worked in confined areas. Both ferrous (cast, zinc-coated, and stainless) and nonferrous (aluminum, cupronickel, copper, brass, and bronze) welding materials were used. All electrodes apparently were covered. For 8 to 10 years, the welder's chest X-rays demonstrated mottling, and a lung lobectomy revealed dark pigmentation on the visceral pleural surface. The iron concentration (10 μg/ml of tissue) was 20 times the normal amount, and the silica concentration (2.8 μg/ml of tissue) was 30% of the total mineral content. Mild functional impairment was noted in the following pulmonary function parameters (% decrease from predicted values): vital capacity (VC), 4%; inspiratory capacity (IC), 15%; residual volume (RV), 52%; and functional residual capacity (FRC), 29%. A massive conglomerate fibrosis was diagnosed. Tuberculosis was suspected but not confirmed because lung cultures were not taken. The pulmonary changes were attributed to the iron and silica in the electrode coatings.

Levy and Margolis [1974] described the case of a 35-year-old man with siderosilicosis of the lung, diffuse interstitial fibrosis, and atypical alveolar epithelium associated with cancer of the lung. The subject was employed as an oxyacetylene cutter in a steel foundry for 5 years; he wore a welder's helmet for eye protection but used no specific respiratory protection. The torch-cutting was performed approximately 4 m from sandblasting operations. Within the work area, the concentration of respirable silica was reported to be 6.82 mg/m^3 and the quantity of iron oxide was 19.4 mg/m^3. The welder had no previous occupational exposure to fibrogenic dusts. A lung X-ray revealed a fine reticular pattern in both lung fields. Pulmonary function studies indicated an obstructive and restrictive ventilatory impairment accompanied by arterial hypoxemia and compensated respiratory alkalosis. X-ray diffraction analysis of lung biopsy tissue revealed iron oxide and silica.

A lung biopsy analysis reported by Brun et al. [1972] of an arc welder who had worked for 16 years on stainless steel in an area with poor ventilation indicated the presence of diffuse fibrosis. Prior medical history revealed that he had suffered dyspnea combined with an asthma-like bronchitis. Examination at the time of the report revealed rales at both lung bases, fine bilateral micronodular reticulation, and the presence of numerous macrophages laden with ferric oxide (siderophages) in the sputum. Respiratory function tests revealed a moderate respiratory deficit: vital capacity (VC) was 73% of the predicted value, and the forced expiratory volume in 1 second (FEV_1) was 65% of the predicted value. Microscopic examination of biopsy material revealed intra-alveolar fibrosis. Numerous histiocytes and macrophages filled with iron were present in the fibrositic wall.

Stettler et al. [1977] reported two cases of siderosis in which the severity of disease appeared to be associated with the welding fume composition. One worker arc welded primarily in open spaces, whereas the second worker arc welded primarily in confined spaces. The authors did not state the age of the workers, the length of employment, or the base metal(s) welded by the two workers. Lung biopsy specimens from both welders, and air samples from the workplace environments were analyzed by electron microscopy using energy dispersive X-ray analysis to determine the chemical composition of the observed particulate matter. The majority of particles in the lungs of both welders were determined to be from stainless steel welding fumes and were comprised mostly of iron with some chromium, manganese, and nickel. In addition, silica, aluminum, and various silicate particles were found in each biopsy preparation. The same types of particles were also found in air samples collected at the worksite during arc welding operations. Although both welders were considered to have siderosis, the first welder had moderate lung disease with minimal interstitial fibrosis, while the second welder had severe respiratory impairment with extensive interstitial fibrosis. The authors concluded that the severity of the disease in the second welder may have been due to the concentration of aluminum particles found in this welder's lungs, which was six times that of the other welder. The authors attributed this increase to his working in a confined space.

Stanescu et al. [1967] examined 16 arc welders (12.1 years average exposure) who had chest X-rays suggestive of siderosis and who had more than 7 years of experience. He found that seven suffered from exertional dyspnea. Although spirometric values (i.e., VC, FEV_1, total lung capacity [TLC], and RV) were generally within normal limits, the authors found a statistically significant ($p<0.05$) decrement in pulmonary compliance when these 7 welders were compared with 13 workers who were not exposed to welding fumes. The authors attributed this decrease either to iron deposits per se or to associated fibrosis caused by other chemical exposures. No mention was made as to whether or not the welders' smoking habits or ages were considered.

In contrast to the decrements in pulmonary compliance found in welders by Stanescu et al. [1967], Kleinfeld et al. [1969] found no differences between welders and a comparison group when they were given a series of pulmonary function tests. Twenty-five welders were compared with a group of 20 men who resided in the same area but who were not exposed to welding fumes. Occupational histories were obtained from all workers in the study, and clinical examinations were performed, including chest X-rays. The average age of the welders was 48.8 years, and the average age of the comparison group was 46.7 years. Fifty-six percent of the welders and 55% of the comparison group were smokers. The average work experience of the welders was 18.7 years, with a range of 3 to 32 years. Their work included oxyfuel cutting and shielded metal arc welding.

Eight (32%) of the 25 welders showed lung changes on X-rays that were characterized by reticular nodular shadows in both lungs. These changes were absent in members of the comparison group. Pulmonary function values, including FEV, FEV_1, RV, and TLC, were normal for both groups. In addition, none of the clinical tests showed statistically significant differences between welders exposed for more than 20 years and those exposed for fewer than 20 years. At the time of the study, environmental sampling was conducted at the sheet metal fabrication facility where the welders were employed. Concentrations of iron oxide ranged from 0.65 to 1.7 mg/m^3 inside the welders' face shields and from 1.6 to 12 mg/m^3 outside the face shields. Exposure to other fume constituents was not reported. Eight years before the study and just before an improved ventilation system was installed, iron oxide concentrations had ranged from 30 to 47 mg/m^3 in the breathing zones of other welders working at the facility.

(d) Bronchitis/Pulmonary Function

The inhalation of welding fumes and gases have been shown to cause decrements in pulmonary function and the development of other chronic nonmalignant respiratory diseases. Many studies (Doig and Challen 1964; Hunnicutt et al. 1964; Kujawska 1968; Ulrich et al. 1974; Antti-Poika et al. 1977; Akbarkhanzadeh 1980; Keimig et al. 1983; Sjogren and Ulfvarson 1985; Oleru and Ademiluyi 1987) have reported the potential health risk to welders from exposure to fumes and gases of unknown composition. Other studies (Doig and Challen 1964; Glass et al. 1971) have shown a risk of exposure to phosgene resulting from the decomposition of trichloroethylene that may be present in the welding work environment. Several other studies (Hunnicutt et al. 1964; Fogh et al. 1969; Akbarkhanzadeh 1980; Sjogren and Ulfvarson 1985) have demonstrated an association between smoking by welders and an increased risk of developing respiratory disease. The following studies are representative of those collective data.

Kujawska [1968] reported on a study of workers aged 35 to 45 who had been arc welding for at least 10 years, had never been employed in trades that would have exposed them to fibrosis-producing dusts, and had acquired no respiratory diseases before starting work as welders. Two equal groups of welders were randomly selected (total group size not given) and placed in a group according to radiologic changes in the lung. One group of 30 had radiologic changes indicative of siderosis and the other group of 30 had normal lung radiographs. The welders of both these groups performed about half their work in small and confined spaces (e.g., inside boiler tanks). Covered acid electrodes were used most often; basic and rutile electrodes were occasionally used. No identification of potential exposures was reported. The comparison group (controls) consisted of 30 healthy pipefitters, mechanics, and turners. Each of the 90 workers (welders and controls) was given a physical examination including medical history, X-ray, ECG, and lung function tests such as lung volumes and capacities, pulmonary ventilation, and examination of alveolar ventilation. No significant differences in age, height, weight, or length of service were found between groups. The distribution of smokers and nonsmokers was also similar. Complaints of labored breathing (86%) and dry cough (40%) were more frequent in the group of welders with siderotic changes than in the other group of welders (37% and 3%) or controls (10% and 7%). Chronic bronchitis was found only in the two groups of welders, indicating a statistically significant difference ($p<0.05$) from controls. In addition, reduced pulmonary function parameters (including lower values of the VC and FEV_1 and an increase in the ratio of residual volume to TLC) were found in the group of welders with siderotic changes.

Antti-Poika et al. [1977] found simple chronic bronchitis to be more prevalent ($p<0.01$) among 157 electric arc welders than among 108 controls who were employed at the same facility but not exposed to welding fumes. The controls were matched to welders with respect to age, smoking habits, and social class. The prevalence of simple chronic bronchitis was compared with the length and concentration of exposure, but no dose-response relationships were noted. The welders (average age was 36.1 ± 10.1 years) mainly used covered electrodes and had been welding for 3 or more years for at least 3 hours a day. Most worked in engineering shops. Samples of total fumes were collected outside the helmet at the time of the study, and concentrations ranged from 1.0 to 9.0 mg/m^3 as an 8-hour TWA. No historical exposure data were reported.

(i) Phosgene Poisoning

Several cases of respiratory distress and pulmonary function impairment have been attributed to phosgene exposure. For example, Doig and Challen [1964] described seven workers who had been complaining for several months about periodic attacks of mild to severe respiratory distress, cough, chest constriction, and breathlessness while they performed gas metal arc welding. The cause of the problem was attributed to vapors from an inadequately ventilated degreasing tank that contained trichloroethylene. The tank was positioned next to open doors so that air currents carried the trichloroethylene vapor 46 m or more to the welding bay, where it decomposed (as a result of heat and ultraviolet radiation from the arc) and formed phosgene.

In another case of phosgene poisoning, a welder experienced chest congestion, difficult breathing, and coughing while welding metal studs to metal links using gas metal arc welding with carbon dioxide [Glass et al. 1971]. The studs were cleaned in an open bucket of trichloroethylene adjacent to the welding bench, and the still-damp studs were placed on the bench and welded. By the end of the morning, the welder's gloves were soaked with trichloroethylene. Examination of the welder 24 hours after exposure revealed reduced vital capacity and FEV_1, airway obstruction, arterial hypoxia, and impaired carbon monoxide transfer. No exposure measurements were reported.

(ii) Interactive Effects of Smoking and Welding

Hunnicutt et al. [1964] reported on one of the first cross-sectional studies that took into account the smoking habits of welders. The study group consisted of 100 electric arc welders and an equal number of nonwelding workers employed at the same plant who were not exposed to welding fumes. The welders were under 60 years of age and had 10 or more years of welding experience in shipyards. Arc welding was the predominant process that was used. However, no exposure data were reported. The following pulmonary tests were conducted on all individuals: FVC, FEV_1, maximum expiratory flow rate (MEFR), maximum mid-expiratory flow rate (MMF), and maximum breathing capacity (MBC). A statistically significant ($p=0.01$) decrement in welders compared to controls was noted for FEV_1, MEFR, and MMF. Seventy-one percent of the welders and 59% of the controls had a history of cigarette smoking. The combined effects of cigarette smoking and exposure to welding fumes increased the likelihood of impaired pulmonary function. Among smokers, the incidence of abnormal pulmonary function in welders was twice that observed in controls. Complaints of shortness of breath, coughs, expectoration, and wheezing occurred twice as often among welders who smoked as among welders who did not smoke. Radiographic evidence of siderosis was found in 34% of the welders (smokers and nonsmokers combined), but the authors found no correlation between degree of respiratory impairment and radiographic abnormality. Siderosis was not observed in the controls.

Fogh et al. [1969] reported on the examination of a group of 154 electric arc welders (more than half [number not given] were shipyard welders while the remaining were engine/boiler welders), 2 oxyacetylene cutters, and 152 nonexposed comparison workers from the same locations. The authors found an increased incidence of chronic bronchitis with increased tobacco smoking in welders as well as in the comparison group when compared to those workers from both groups who did not smoke. Decreased pulmonary function (i.e., FEV_1) was found to be statistically significant among nonsmoking welders when compared with either the welders or controls that smoked (i.e., <10 cigarettes/day, p=<0.05; >10 cigarettes/day, p=<0.01). No statistically significant difference was shown when welders who smoked were compared with the control group of smokers. Among all the controls, symptoms did not increase with age. However, in welders under and over 50 years of age the prevalence of symptoms was 25% and 55%, respectively (p<0.05). Among the welders who smoked, 26% of those under the age of 50 and 55% of those over 50 displayed increases in bronchitic symptoms. Neither age group differed significantly when compared to the same age groups of smokers in the comparison group. Chest X-rays revealed a fine mottling indicative of siderosis in five welders (3%). No exposure data were reported.

Barhad et al. [1975] reported on the prevalence of respiratory symptoms and the impairment of ventilatory function in a group of 173 shipyard welders who had 5 or more years of welding experience. The average age was 34.1 years (range: 22 to 57). Cough was found to be increased 22% and chronic bronchitis 20% in welders when compared to a control group of workers from the same shipyard but with no welding fume exposure. The prevalence of chronic bronchitis was 1.5 times more frequent among welders when compared to controls; the difference in prevalence tended to be larger in nonsmokers (12% of welders versus 3% of controls) as compared to smokers (26% of welders versus 21% of controls) but the limited number of observations precluded any statistical analysis. Dyspnea and wheezing (p<0.001) and paroxysmal dyspnea (p<0.005) were approximately two times more common among welders (smokers, ex-smokers, and nonsmokers) when compared to controls matched for age and smoking habits. The major type of welding was arc with some oxyacetylene torch and shielded welding. At the time of the study, breathing zone welding fume concentrations were found to range from 6 to 36 mg/m^3 while welding in open work areas and 48 to 92 mg/m^3 in confined spaces. Nitrogen oxide exposures averaged 1.7 mg/m^3 for shielded and 1.1 mg/m^3 for arc welding. Carbon monoxide exposures averaged 17 mg/m^3 for torch welding, 8.4 mg/m^3 for electrical, and 6.3 mg/m^3 for flux welding. No historical exposure data were reported.

A similar type of analysis of shipyard welders was performed by Akbarkhanzadeh [1980]. A study was initiated to determine the influence of welding fumes and cigarette smoke on the bronchopulmonary system. The study included 209 welders with 1 or more years of welding experience (mostly shielded metal arc) and a comparison group of 109 shipyard workers who were not exposed to welding fume and who worked for at least 10 years in the same work environment. The welders and the comparison group were divided into smokers, ex-smokers, and nonsmokers. The durations of exposure for welders who smoked (22.5 years) and those who did not smoke (20.9 years) were similar. The smoking habits of the welders and the comparison group were reported to be identical. Persistent cough and phlegm were found to be twice as frequent among welders who smoked (16.7%) as among the comparison workers who smoked (8.3%). Chronic bronchitis was found only in welders (12.4%) who smoked or had smoked. The mean duration of exposure for these welders was 30 years.

For all welders the FEV_1 was less (3.77) than that of the total comparison group (4.03) and less for the nonsmoking welders (3.92) when compared to the controls who did not smoke (4.27). Differences observed for both groups were statistically significant ($p<0.025$). Although the FEV_1 was lower among welders who smoked when compared to controls who smoked (3.63 versus 3.82), the difference was not statistically significant. The FVCs for smoking (4.91) and nonsmoking (5.10) welders were lower than the corresponding smoking/nonsmoking (5.07 and 5.40, respectively) comparison groups. These differences were not statistically significant. With advancing years of exposure, all lung function parameters of welders deteriorated more than those of workers in the comparison group. No exposure data were reported.

A cross-sectional study was reported by Keimig et al. [1983] on the prevalence of respiratory symptoms or impaired lung function in welders exposed to fumes and gases from gas metal arc welding and flux core welding on mild steel. Welders and controls were white males, aged 25 to 49 and were employed for at least 4 years at a plant that manufactured heavy construction equipment. The study group was comprised of 91 welders (46 nonsmokers, 45 smokers) with a mean welding exposure of 108 months, and 80 controls (35 nonsmokers, 45 smokers) who were employed at the same plant but had jobs with minimal exposure to respiratory irritants. Occupational and smoking histories were collected from all subjects. The types of pulmonary function tests given and the questionnaire administered to all subjects were in accordance with the guidelines of the American Thoracic Society. Measurements of pulmonary function were made on each subject before and after each work shift.

As expected, welders and controls that smoked reported a higher frequency of respiratory symptoms (e.g., bronchitis, pneumonia, cough) than corresponding nonsmokers. Although welders who did not smoke reported higher frequencies of symptoms than nonsmoking controls, the differences were statistically significant ($p<0.05$) for only the symptoms of increased phlegm and episodes of cough and phlegm. Pulmonary function measurements were compared both within and between welders and controls, and by smoking status. Predicted normals were not used in the statistical analysis. The only statistically significant differences noted were decreases in forced vital capacity (FVC) measurements at the end of the work shift for nonsmoking welders, nonsmoking controls, and smoking controls. The authors concluded that these differences were not attributable to welding exposure, because controls as well as welders showed a significant decrease. Nonsmoking welders and smoking welders compared to respective controls did not have significantly decreased mean values of FVC or forced expired volume in 1 sec (FEV_1). The mean expiratory flow rates and forced expiratory flow rates measured at 75% of the FVC were found to be lower but not significantly different for welders when compared to controls. Breathing zone air samples collected near welders at the time of the study indicated iron oxide concentrations of 1.3 to 8.5 mg/m^3. No detectable amounts of chromium, copper, fluoride, and lead were found in any of the air samples.

A more detailed cross-sectional study was described by Sjogren and Ulfvarson [1985] who assessed the respiratory symptoms of cough, phlegm, and irritation; chronic bronchitis; and pulmonary function of male welders in Sweden. Welders were identified from the Swedish Register of Enterprises, Bureau of Statistics, and placed into three study groups: those who welded using gas metal or tungsten arc on aluminum (Group 1); those who welded with coated electrodes on stainless steel (Group 2); and those who welded on railroad tracks (Group 3). To be included in the study, each welder must have worked at least 1 year, spending at least 3.5 hours per workday performing the type of work identified above. No specific restrictions on the amount of welding time per day were applied to Group 3. All workers who were asked to be in Groups 1

(64 welders) and 2 (46 welders) agreed to participate. The median exposure time was 5 years (range: 1 to 24) in Group 1 and 15 years (range: 1 to 39) in Group 2. A total of 149 welders who were asked to be in Group 3 agreed to participate. A nonwelding comparison group was chosen for Groups 1 and 2 from the same companies and were matched by age (with a variance of 4 years) and smoking habits. The comparison group for Group 3 included 70 railroad workers who did not weld. This group was not matched for age or smoking habits.

All three groups of welders had higher frequencies of chronic bronchitis than their respective comparisons, but the differences were statistically nonsignificant and appeared to be more dependent on smoking than on welding fumes [Sjogren and Ulfvarson 1985]. However, overall respiratory symptoms were more prevalent for welders working with gas-shielded welding on aluminum (Group 1) than the comparison group, and were statistically significant (p=0.03) with increasing exposure to ozone. Exposure to ozone rather than to aluminum fumes appeared to be responsible for the excess in the observed respiratory symptoms of Group 1 welders [Sjogren and Ulfvarson 1985]. Almost 50% of the exposures to ozone exceeded 0.1 ppm when gas metal arc welding was performed on aluminum. Likewise, welders in Groups 2 and 3 displayed more respiratory symptoms with increasing chromium exposures, but the difference was not statistically significant. More than 80% of the hexavalent chromium exposures exceeded 20 $\mu g/m^3$ when stainless steel was welded with coated electrodes.

According to the authors, respiratory symptoms were not related to total fume concentrations (concentrations not stated) or nitrogen oxides (<5 ppm). No differences were observed regarding FVC or FEV_1 between the three groups of welders and their respective comparison groups.

Oleru and Ademiluyi [1987] reported the results of pulmonary function measurements made on workers engaged in welding and thermal cutting of window and door frames made from medium and high alloy steel and aluminum. A group of 67 (36.8%) from a total of 182 men in the workforce were evaluated for decrements in pulmonary function. Of the 67 subjects, 16 were maintenance workers who were indirectly exposed to welding fumes and gases; 13 were engaged in mild steel welding and 7 were engaged in mild steel cutting; 18 were involved in aluminum cutting operations; and 13 were responsible for the paint dipping of metal frames. A modified British Medical Council respiratory disease questionnaire was administered to all subjects. Lung function assessments including peak expiratory flow rate (PEFR), one second forced expiratory volume (FEV_1), and forced vital capacity (FVC) were made with a Wright's peak flow meter for PEFR and a Vitalograph spirometer for FEV_1 and FVC. To assess the potential acute respiratory effects that may have occurred over a work-week (40 hours) 8 of the 13 mild steel welders were given spirometric tests on Monday morning and after the work shift on Friday. To measure possible pulmonary function changes that may have occurred after an 8-hour work shift and 3 consecutive work shifts, the peak flow test was administered to all 13 welders and 13 paint dippers before and after the work shifts on Wednesday and Friday. The expected lung function parameters of the subjects were calculated from the pulmonary function equations developed for a group of normal, non-industrially exposed Nigerian subjects. Only 9 of the 67 subjects were found to have ever smoked with an average cigarette comsumption of less than 5 per day and an average duration of about 4 years.

Although not statistically significant, those workers classified as maintenance workers had higher lung function measurements (FEV_1 and FVC) than the other groups of workers. However, there was no evidence of obstructive lung disease among any of the groups as supported by the high FEV_1/FVC ratios observed for all subjects, with the lowest 95% confidence interval for any group being 87.6% to 84.2% found for the maintenance workers. Seven cases of restrictive lung impairment were observed among the subjects--3 paint dippers, 2 aluminum workers, and 2 welders. All complained of coughing, chest pains, and difficulty in breathing. The length of employment for these cases ranged from 3 to 7 years. The eight welders who were given spirometric lung function tests to assess the effects of exposure over a work week (40 hours) demonstrated statistically significant ($p<0.05$) decrements in all parameters measured. Peak flow measurements made on this group after an 8-hour work shift showed acute changes in pulmonary function that were statistically significant ($p<0.05$); however, these changes in pulmonary function were not found to be significantly different when welders were tested at the end of three consecutive work shifts. Statistically significant ($p<0.005$) changes in peak flow measurements were observed for the 13 paint dippers when tested after either an 8-hour work shift or 3 consecutive work shifts.

The absence of any obstructive lung disease among the exposed subjects is consistent with the low number of subjects who smoked. The analysis of spirometric and peak flow rate data gathered on a small number of welders and paint dippers after 8-, 24-, and 40-hour work shifts did demonstrate statistically significant changes in lung function. However, because of the low participation rate (36.8%) it is not possible to determine the significance of these data. Although no exposure data were collected, the authors hypothesized that based on the amount of settled dust that had accumulated in the work area, airborne dust concentrations probably exceeded 5 mg/m^3.

(e) Summary--Nonmalignant Pulmonary Diseases

The acute respiratory diseases metal fume fever and pneumonitis have been observed in workers involved in many types of welding processes. Several studies have shown the occurrence of metal fume fever in workers exposed to mixed fume compositions [Ross 1972; Johnson and Kilburn 1983] and to specific metals [Drinker 1922; Drinker et al. 1927]. In all cases, workers experienced nonspecific systemic reactions, including eye and throat irritation, headache, shortness of breath, and nausea that usually ceased within 24 hr after removal from exposure. Likewise, welders' pneumonitis has been documented in several case reports and cross-sectional morbidity studies that have shown exposures to the mixed fume composition [Kleinfeld et al. 1957; Beton et al. 1966; Townshend 1968; Blejer and Caplan 1969; Patwardhan and Finckh 1976; Jindrichova 1976; Herbert et al. 1982] and gases [Molos and Collins 1957; Challen et al. 1958; Maddock 1970; Mangold and Beckett 1971] to be a causative factor in the observed cases of respiratory distress, pulmonary edema, and diminished pulmonary function. Except for limited exposure data reported by Kleinfeld et al. [1957], Molos and Collins [1957], and Challen et al. [1958], all the above studies lacked quantitative exposure data and reported workers being exposed to welding fumes and gases in confined spaces or poorly ventilated work areas. Several fatalities have been observed among workers acutely exposed to cadmium fumes [Beton et al. 1966; Patwardhan and Finckh 1976] and nitrogen dioxide [Maddock 1970].

The occurrence of pneumoconiosis, including siderosis, was first recognized in 1936 among a group of welders [Doig and McLaughlin 1936]. Since then, many case and epidemiologic reports [Britton and Walsh 1940; Sander 1944; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950] have described similar clinical findings of asymptomatic, benign, and radiologically detectable lung changes in welders. Before 1950, much of the welding was performed with bare metal electrodes that produced high concentrations of iron oxide. Since the replacement of bare metal electrodes with covered electrodes, the potential for mixed exposure to other metal fumes has increased. As a result of these mixed exposures, there have been subsequent reports of welders in which the complications of fibrosis [Stettler et al. 1977; Meyer et al. 1967], pulmonary impairment [Meyer et al. 1967; Brun 1972; Levy and Margolis 1974], and reticular nodular shadows [Kleinfeld et al. 1969; Attfield and Ross 1978] were identified with siderosis.

Bronchitis and decrements in pulmonary function have been reported in welders who have been involved in many types of welding processes. Welders employed in shipyards have shown statistically significant decrements in pulmonary function [Hunnicutt et al. 1964; Fogh et al. 1969] and increases in chronic bronchitis [Fogh et al. 1969; Barhad et al. 1975; Akbarkhanzadeh 1980]. With the exception of one study [Barhad et al. 1975], in which exposures to welding fume were measured at 6 to 36 mg/m^3 in welders' breathing zones and 48 to 92 mg/m^3 in confined spaces, no exposure data were reported. The interpretation of these studies is complicated by the heterogeneity of welding exposures and the possible presence of asbestos as a concomitant respiratory hazard. Studies reported by Keimig et. al [1983] and Oleru and Ademiluyi [1987] on welders exposed to mild steel fume and gases in industries other than shipyards observed differences in pulmonary function measurements between welders and nonexposed groups but could not differentiate between smoking and welding exposure on the observed changes. Keimig et al. [1983] found a higher frequency of reported symptoms of phlegm and episodes of cough and phlegm for welders who smoked compared to nonsmoking welders. Decrements in pulmonary function parameters were reported by Oleru and Ademiluyi for welders after an 8-hr work shift and at the end of a 40-hr workweek. Although these differences were statistically significant, there was a low participation rate (36.8%) in the study. Several other studies [Mangold and Beckett 1971; Antti-Poika et al. 1977; ACGIH 1986] have shown a statistically significant increase in chronic bronchitis in welders performing different welding tasks when compared to nonexposed comparison groups. In all the studies where chronic bronchitis occurred, the prevalence of the disease increased with the increasing use of tobacco.

(2) Respiratory Cancer

The following assessment of epidemiologic investigations provides information about the possible association between cancer and occupational exposure to welding fumes and gases [Breslow et al. 1954; Dunn and Weir 1968; Ott et al. 1976; HMSO 1978; Blot et al. 1978; Gottlieb 1980; Sjogren 1980; Milham

1983; Beaumont and Weiss 1981; Polednak 1981; Becker et al. 1985; Newhouse et al. 1985; Steenland et al. 1986; Schoenberg et al. 1987; Sjogren et al. 1987]. Many of the studies report standard mortality ratios (SMRs) greater than 100 or odds ratios (ORs) above 1.0, which suggests an increased risk of respiratory cancer. However, some of these studies are not statistically significant and many do not account for the confounding factors of smoking or possible asbestos exposure. To facilitate discussion, the studies have been grouped as cohort mortality or case-control studies. To permit comparison of study results, summaries of these studies (including information on study design, observed/expected numbers, SMRs, ORs, etc.) are presented in Tables IV-3 and IV-4.

(a) Cohort Mortality Studies

The study reported by Sjogren [1980] of Swedish welders has been the only cohort mortality study to specifically assess the association between lung cancer mortality and exposure from welding on stainless steel. The study cohort included 234 nonasbestos-exposed stainless steel welders who had a minimum of 5 years exposure between 1950 and 1965. The cohort was followed through December 1977. Of the 234 welders, 207 welded with covered electrodes most of the time. An OR of 4.4, based on three lung cancer deaths ($p<0.03$), was observed among the stainless steel welders when compared to Swedish death rates. All three welders who died of lung cancer were cigarette smokers. The OR was still statistically significant at $p<0.05$ after adjusting for a theoretical 10% increase in cigarette smoking among stainless steel welders. No exposure data were available for the study cohort; however, measurements of chromium taken in 1975 at a similar stainless steel welding process revealed median TWA chromium concentrations of 210 $\mu g/m^3$ while welding with covered electrodes and 20 $\mu g/m^3$ during gas-shielded welding. The author stated that only a minor fraction of the exposure was in the hexavalent form; therefore, the concentrations were an overestimate of hexavalent chromium exposure.

In 1987, Sjogren et al. [1987] reported on the follow-up analysis of these 234 stainless steel welders who were exposed to high concentrations of chromium. After 7 years of additional follow-up, the mortality of this cohort was reanalyzed and the results compared to another cohort that consisted of 208 railway track welders exposed to low concentrations of chromium (<10 mg/mg^3). The participants of both cohorts had welded for at least 5 years sometime between 1950 and 1965 and were followed for mortality until December 1984. The expected number of deaths in the two cohorts were calculated by the multiplication of the person-years of observation within 5-year age categories during 1955-1984 by cause-, gender-, age-, and calendar-year-specific national death rates of Sweden. An increase in deaths (SMR=249) from respiratory cancer was observed for the cohort of welders who were exposed to high concentrations of chromium. In contrast, deaths from respiratory cancer in the low-exposure cohort of welders were less than expected (1 death observed, 3 deaths expected). When welders who had high exposures to chromium were compared with those who had low exposures, the number of deaths from respiratory cancer was significantly elevated in the high exposure group, which had a relative risk of 7.01 (95% CI = 1.32-37.3). No other statistically significant increase in deaths from other causes was observed in either cohort. The authors noted that the expected number of deaths from respiratory cancer reported in the earlier analysis by Sjogren [1980] were incorrectly calculated as 0.7 instead of 0.9, resulting in an OR of approximately 3.3 (estimated by NIOSH). No correction for smoking habits was made when either cohort was compared with the expected national death rates. However, smoking as a confounder was not considered to have a significant influence on the comparison of lung cancer risk between the two cohorts of welders.

Becker et al. [1985] reported on a retrospective mortality study of 1,224 welders and 1,694 turners (machinists) who were employed in 25 German factories from 1950-1970 and followed until 1983. The death rates of welders were compared with the death rates from internal and external comparison groups. The internal comparison, based on the death rates of turners not exposed to nickel or chromium, yielded a statistically significant OR of 2.4 for welders ($p<0.05$) for all cancers and a statistically nonsignificant OR of 1.7 for cancer of the trachea, bronchus, and lung. External analyses (German National death rates) showed that the SMRs for all cancers; cancer of the trachea, bronchus, and lung; and respiratory diseases were statistically less than expected ($p<0.05$). Increases in ORs and SMRs for welders who used covered electrodes and who had greater than 20 or 30 years latency were observed for all cancers, including cancer of the trachea, bronchus, and lung, when compared to the internal comparison group. Since the method of age adjustment was not given, it was impossible to determine what bias the difference in age distribution of the internal comparison group may have contributed to the results. No historical exposure data were reported.

A retrospective mortality study of 3,247 welders from Seattle, Washington, was reported by Beaumont and Weiss [1981]. The cohort of welders was selected from local union records of the International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers, and Helpers. The welders had a minimum of 3 years of union membership and had worked between 1950 and 1973. A majority of them had been employed at shipyards or metal fabrication shops. An SMR of 132 (p=0.06) for lung cancer was observed when death rates for U.S. white males were used for comparison. The SMR for lung cancer in welders rose to 174 (p<0.001) when the investigators considered the 39 deaths that occurred 20 or more years after first employment. No historical exposure data were reported, especially data regarding exposure to asbestos in shipyards. Likewise, the potential effect of cigarette smoking on the observed excess in lung cancer was not determined. Internal comparison of welders and nonwelders revealed an excess lung cancer risk that was found to be greater among welders employed 20 or more years following first exposure.

In 1986, Steenland et al. [1986] reported on a reanalysis of the Beaumont and Weiss [1981] study using the Cox and logistic regression analyses to compare lung cancer risk of welders. These analyses were thought to be preferable because they use an internal nonexposed comparison group that is more likely to have lifestyles (e.g., smoking habits) similar to the exposed group. The Cox regression analysis compared welding as either a dichotomous or continuous variable with time-since-first-employment and year-first-employed. The logistic regression was used to analyze the 137 lung cancer deaths (cases) and the remaining 8,542 study subjects (controls). Of the total number of controls, 3110 were welders while the remaining 5,432 were other members (e.g., shipfitters, riggers) of the same union who were frequently employed in the same place as the welders. Men who died of lung cancer were compared to men who did not and an OR for lung cancer was determined for welders versus nonwelders.

When welding was analyzed as a dichotomous variable, a statistically significant interaction was observed with year-first-employed (OR=152, p=0.03). An OR of 1.29 (p=0.03) for lung cancer was observed among welders when welding was considered as a cumulative dose in the logistic analysis. An elevated OR of 1.15 still remained for lung cancer among welders when cumulative dose was analyzed in the Cox regression.

In a mortality analysis of 1,027 shipyard welders employed from 1940 to 1968 in Northeast England, Newhouse et al. [1985] reported elevated SMRs for all cancers (SMR=114), and for lung cancer (SMR=113) after excluding mesothelioma. Accurate dates of employment were not available, so analysis by latency and duration of employment was not made. No smoking histories or information on exposures were cited.

Another mortality study of 2,190 Italian shipyard workers in Genoa, Italy was reported by Puntoni et al. [1979]. The study population consisted of working or retired workers as of January 1, 1960 and followed until December 31, 1975 (duration of employment not given). Age- and sex-specific mortality ORs were calculated for 19 occupational groups including electric and gas welders and compared with two comparison groups: the entire male population of Genoa and the male staff of St. Martin's Hospital in Genoa. Overall, the shipyard workers had statistically significant ORs for total deaths and several specific causes of death including all cancers and cancer of the trachea, bronchus, lung, and larynx when compared to the male population of Genoa, Italy. Gas welders had statistically significant increased ORs for total deaths ($p<0.0005$) and respiratory diseases ($p<0.05$), when compared with the same comparison group. No statistically significant excess in lung cancer was noted for either electric or gas welders.

Although no exposure data were reported, the authors cited exposures to other potential carcinogens (e.g., asbestos, aromatic and halogenated hydrocarbons) in the work environment. The smoking habits of the workers were not assessed nor was the study population age-adjusted. The study consisted of a survivor population, with terminated workers not included in the analysis. The absence of terminated workers probably biased the distribution of deaths because of the many long-term workers.

Polednak [1981] reported on a study of 1,059 white male welders from 3 nuclear facilities in Tennessee. Increases of SMRs were found for lung cancer (SMR=150) and diseases of the respiratory system (SMR=133) that were not statistically significant when compared to U.S. white male death rates. Welders were selected for the cohort if they were hired between 1943 and 1973. SMRs for lung cancer (SMR=175) and respiratory disease (SMR=167) were higher among welders not exposed to nickel oxides than for welders exposed to nickel oxides (SMR=124 for lung cancer, SMR=101 for respiratory disease). Two smoking surveys conducted in 1955 and 1966 showed that cigarette smoking among the group of welders who were not exposed to nickel oxides was 2.5 times more prevalent than the nickel oxide exposed group. About 20% of the welders exposed to nickel oxide smoked cigarettes during the years surveyed. The difference in smoking habits may account for the higher SMRs for lung cancer and respiratory disease among the nonexposed group of welders. In relation to duration of employment in all welders, the lung cancer SMR was elevated for those who worked more than 50 weeks, while the respiratory disease SMRs were higher for those with shorter durations of employment. The fume exposures of welders were causally implicated in the increased risk of respiratory diseases, including pneumoconiosis and bronchitis. At the facility where nickel alloy pipes were welded, time-weighted average (TWA) air concentrations of nickel found in 1975-1977 were all higher than 0.015 mg/m^3 (range of concentrations not given). The sample size of the two subgroups of welders was small, and 8.3% of the study cohort was of unknown vital status at the end of the study period. The nonexposed welders were slightly older than those exposed which may have contributed a negative bias to the SMRs.

In a prospective mortality study reported by Dunn and Weir [1968] a slight, but not statistically significant, excess of lung cancer deaths (OR=1.05) was observed for welders and burners studied over an 8-year period. The study design, which included 13 other occupational groups ascertained from California union records, was based on the information gained from 121,314 mailed questionnaires (85% response rate). Statistical analyses were conducted using age- and smoking-specific death rates, and compared with the death rates of the total union population. No exposure measurements were made and employment records were unavailable. Potential exposures were estimated from the general occupational information that appeared on the questionnaire provided by the respondent.

Milham [1983] reported a statistically significant increase in proportional mortality ratios (PMRs) observed for male welders and flamecutters for several causes of death. The proportional mortality study was based on death certificates collected over a 29-year period (1950-1979) in Washington State.

The statistically significant PMRs are reported in Table IV-5. Occupations were derived from death certificates, which were reported to be inaccurate for as many as 30% of the deaths. The study consisted of a survivor population with deaths of terminated workers not included in the study analysis. Smoking and the potential exposure to asbestos were not accounted for and could have had an effect on the outcome of the study.

In a review of lung cancer rates (by occupation) for Los Angeles County, Menck and Henderson [1976] observed a significantly increased SMR of 137 ($p<0.05$) for welders when compared to the age-, race-, and sex-adjusted Los Angeles County employed population. A total of 2,161 death certificates cited lung cancer as the cause of death in white males, ages 20 to 64, during the periods 1968 to 1970. In addition, 1,777 cases of lung cancer in white males during 1972 and 1973 in Los Angeles County were used. Neither the potential effect of asbestos exposure nor smoking habits were assessed in the study analysis.

Table IV-5.--Statistically significant PMRs[a] for welders and flamecutters[b,c]

Cause of death	Observation period 1950-59	1960-69	1970-79	1950-79
<u>Cancer</u>:				
Respiratory system	--[d]	--	136	126
Trachea, bronchus, lung	--	--	136	135
Kidney	--	--	234	182
<u>Nonmalignancies</u>:				
Diseases of respiratory system	164[e]	137[e]	103	122[e]
Chronic bronchitis	--	382	--	256
Bronchitis with emphysema	--	397	--	259
Other	255[e]	--	--	--
<u>Accidents</u>:				
Fires and explosions	314	--	321	229

[a] Proportional mortality ratio.
[b] Adapted from Milham [1983].
[c] $p<0.01$ unless otherwise noted.
[d] Dash indicates $p>0.05$.
[e] $p<0.05$.

Occupation and type of industry were ascertained from death certificates (which only listed last job held) and medical records. Thus a clear delineation of all jobs held, years of employment, and potential occupational exposures could not be made.

In the report published by Her Majesty's Stationary Office [HMSO 1978] of England and Wales, increased mortality caused by pneumonia, lung cancer, and other and unspecified respiratory cancer was observed for gas and electric welders, cutters, and brazers during the period 1970-72. An overall increase (22%) in deaths was recorded even after adjustment for smoking, age, and social class. This was more than was expected for this occupational group. A statistically significant increase ($p<0.01$) in the PMR for lung cancer mortality was found among smokers and nonsmokers. This risk remained statistically significant with an SMR of 116 ($p<0.01$) when controlled for smoking. The number of lung cancer cases recorded in 1966-1967 and 1968-1969 were noted as "particularly" high. In 1968-1969, seven cancer cases were recorded for other and unspecified respiratory organs, whereas only one was expected. Although no explanation was provided, the authors attributed the excess in lung cancer to an association with asbestos exposure. Possible errors in the analysis could have resulted from differences in the occupational classifications used for the numerator and denominator in determining PMRs. Numerator estimates were based on occupations given in death certificates, whereas the denominator used occupations found in the national census data. Therefore, the rates reflect some bias (unknown direction) in their estimation of risk. Although this type of mortality study (which relies on routinely collected data) is useful for identifying associations between occupation and mortality, it is imprecise for detecting complex relationships between cause of death, exposure, and occupation. No information on the types of exposures were available for analysis. Smoking habits were not assessed but were controlled by using a 22% over-incidence for smoking in the analysis.

Ott et al. [1976] reported on a cohort mortality study of 8,171 male workers employed at a chemical facility. The study population was subdivided into two cohorts; the one cohort consisted of those workers (5,994) hired before 1950 and the other consisted of workers (2,177) hired between January 1950 and March 1954. The vital status of all workers was followed until 1973. Analysis of malignant neoplasms was ascertained for 15 job categories including welders and lead burners. Based on 12 malignant neoplasm deaths, welders and lead burners had an elevated but not statistically significant SMR of 162 when compared to U.S. white male death rates. It was not possible to validate the increase of lung cancer based on two observed lung cancer deaths. Although workers who were potentially exposed to arsenicals or asbestos were eliminated from the study, no further characterization of other potential exposures was provided. A potential misclassification bias could have been introduced because workers were assigned job categories based on their job titles the day they were hired; subsequent job changes were not taken into account.

(b) Case-Control Studies

Gerin et al. [1984] reported on a case-comparison study of hospital cancer patients and their possible occupational exposure to nickel. Lung cancer risk was determined on case ascertainment from 17 hospitals in Montreal, Canada. A statistically significant dose-related OR of 3.3 (95% CI=1.2 to 9.2) was reported for patients who were classified as stainless steel welders "exposed to nickel." Welders identified as having no nickel exposures did not have a statistically significant excess risk. Lung cancer patients identified as nonwelders, but who were exposed to nickel, had a statistically significant OR of 2.9 (95% CI=1.3 to 5.7). The potential for exposure to nickel and chromium were highly correlated, with 78 out of 79 cases exposed to both nickel and chromium. Analyses were controlled for age, smoking history, socioeconomic status, ethnicity, and unknown hospital referral patterns. Occupational exposure to nickel was derived from the patients' responses to a semi-structured questionnaire administered by a team of chemists and industrial hygienists who were unaware of the cancer status. The cases were not controlled for a potential asbestos exposure.

A similar case comparison study was conducted by Breslow et al. [1954] of 518 lung cancer patients from 11 California hospitals during 1949-1952. Of the 518 lung cancer patients, 14 (10 welders and 4 sheet metal workers) were classified as having occupations that exposed them to welding fumes. Although no exposure data were presented, the 14 lung cancer patients were probably exposed to welding fumes associated with the use of arc welding and bare metal electrodes, because this was the primary method of welding prior to 1950. An equal number of patients admitted to the same hospital but whose diagnosis was not cancer or respiratory disease, were used as controls and matched for age, race, and sex. A questionnaire was given to lung cancer patients and the controls to determine occupations, tobacco use, and exposure to toxic materials. The 14 lung cancer patients who were probably exposed to welding fume represented a statistically significant ($p<0.05$) occupational group even after adjustment for cigarette smoking.

Gottlieb [1980] observed a statistically significant OR of 1.19 for white and black males (combined) in a case-control study of lung cancer mortality among all workers employed in the Louisiana petroleum industry between 1960-1975. When the relative risks were determined for welders and were stratified by age at death, only the relative risk for welders under age 60 remained elevated at OR=1.89 (95% CI=0.5 to 7.4), suggesting an occupational etiology. Controls were selected from noncancer deaths and matched to the cases individually by sex, race, year of death, parish of residence, and age at death. A survivor bias may have existed because of death certificate identification of the study population. Smoking habits and the potential for asbestos exposure were not included in the analysis.

In an effort to determine the cause of the high rate of lung cancer among male residents of 11 coastal counties of Georgia, a case control incidence study was conducted by Blot et al. [1978]. Cases were identified from hospital records, and death certificates were obtained for lung cancer patients. Controls were selected from hospital admissions and death certificates, and were matched (two controls for every case) closely by sex, race, age, residence, and vital status. A questionnaire was given to patients and controls (or the next of kin) to determine place, type, and length of employment for any job held for 6 months. Patients who had been employed in a shipyard, had an OR of 1.6 (95% CI=1.1 to 2.3, p=0.006) for lung cancer. The 11 patients who were welders or who were exposed to welding fumes had a crude relative risk of 0.7. Although the relative risk of those employed at shipyards was adjusted for cigarette smoking, asbestos exposure, age, race, and sex, the crude relative risk among welders was not adjusted and, therefore, may not be a reliable estimate of cancer incidence.

In contrast to the study reported by Blot et al. [1978], Schoenberg et al. [1987] found an increased risk of lung cancer among welders employed in shipyards who had no reported asbestos exposure. These results were observed in a case-control study that included 763 white males with histologically confirmed primary cancer of the trachea, bronchus, and lung and 900 general population white male controls. All cases and controls were selected from six geographical areas of New Jersey with risk estimates determined by either job title or industry job title category. The effects of smoking and other potential confounders were examined. A more detailed analyses was conducted for shipbuilding workers and included comparisons of risk by job category and by reported exposure to asbestos. Personal interviews of all cases and controls, or their next of kin, were conducted to collect demographic data, information on personal and environment risk factors, smoking history, and diet.

Of the 42 job title categories examined, 15 were considered to be at high risk, with printing workers, janitors, and cleaners having statistically significant (p>0.05) increased smoking-adjusted ORs; 11 had smoking-adjusted ORs of 1.3 or greater, while 4 categories with small numbers of subjects had crude ORs greater than 1.3. Of the 34 industry job title categories examined, 13 were considered to be at high risk. Shipbuilding workers, as well as trucking service warehousing and storage workers, had statistically significant (p>0.05) increased smoking-adjusted ORs.

The risk for lung cancer among shipbuilding workers was found primarily among subjects with reported nonincidental asbestos exposure. An increased OR both for latency of less than 30 years (OR of 3.9) and for latency of 30-39 years (OR of 1.7) was observed for these workers. When shipbuilding workers were further analyzed by shipyard job category, welders were observed to have a statistically significant increased OR of 3.8 (95% CI=1.8 to 7.8). Of the 33 cases and 18 controls classified as welders, 16 cases and 7 controls were reported to have been exposed to asbestos. When the remaining 17 cases and 11 controls who had no reported asbestos exposure were analyzed, an increased smoking-adjusted OR of 2.5 (95% CI=1.1 to 5.5) remained.

A case-control study was conducted by Olsen et al. [1984] to assess the elevated laryngeal cancer risk found among white males in Denmark, and to determine if any association existed between these cases and exposure to welding fumes. The study population was composed of 271 incident cases of cancer of the larynx and 971 population controls matched on date of birth, sex, and residence. Patients and controls were interviewed to determine occupations, potential exposures, and tobacco and alcohol usage. Based on the analysis of 271 cancer patients during 1980-1982, workers exposed to welding fumes had a statistically significant increased OR of 6.3 (95% CI=1.8 to 21.6) for cancer of the subglottic area of the larynx. An elevated but not statistically significant OR of 1.3 (95% CI=0.9 to 2.0) was observed for cancer of the larynx. After adjustment for quantified tobacco and alcohol usage, the relative risks persisted. When the study was restricted to 12 stainless steel welders, only the relative risk for subglottic cancer remained elevated with an OR of 6.7 (95% CI=1.0 to 33.3).

(c) Summary--Respiratory Cancer

Several of the epidemiologic studies demonstrated statistically significant increased risks for lung cancer among male welding populations [Breslow et al. 1954; HMSO 1978; Sjogren 1980; Beaumont and Weiss 1981; Milham 1983; Gerin et al. 1984; Steenland et al. 1986; Schoenberg et al. 1987; Sjogren et al. 1987]. Four of these studies showed statistically significant dose-response relationships, one with an increasing observation period and duration of welding exposure [Beaumont and Weiss 1981], two with exposures to nickel and chromium during welding of stainless steel [Sjogren 1980; Gerin et al. 1984; Steenland et al. 1986; Schoenberg et al. 1987; Sjogren et al. 1987], and a case control study [Schoenberg et al. 1987] of shipyard welders that was controlled for smoking and accounted for possible asbestos exposure. In one study [Gerin et al. 1984], the contribution of cigarette smoking habits to lung cancer risks was used as a control, while the other study [Sjogren 1980] used a crude estimate of smoking habits (10% more welders who smoke) as the control. The two other studies [Steenland et al. 1986; Sjogren et al. 1987] reaffirmed the excess risk of lung cancer observed by Beaumont and Weiss [1981] and Sjogren [1980]. Steenland et al. [1986] found an elevated risk of lung cancer among the study cohort reported by Beaumont and Weiss [1981] when they used an internal comparison group that shared similar lifestyles (e.g., smoking) and occupational exposures (e.g., asbestos). Likewise, Sjogren et al. [1987] observed that the risk of lung cancer remained increased when the study group that was used in a previous study [Sjogren 1980] was compared to another group of welders who were exposed to lower concentrations of chromium. The remaining three studies [Breslow et al. 1954; HMSO 1978; Milham 1983] support an association between welding exposures and increased risk of lung cancer. One of these three studies made adjustments for the contribution of cigarette smoking to the proportion of welders with lung cancer [Breslow et al. 1954]. The other two studies [HMSO 1978; Milham 1983], although based on national data sets, are relevant since analyses of these types of data are usually not considered sensitive enough to detect the kinds of complex relationships (exposure and effect) observed unless the disease is rare and the occupational association considerable.

In addition to the above cited studies, a study of welders in the Louisiana petroleum industry also showed a statistically significant lung cancer risk [Gottlieb 1980]. However, when the study group was adjusted for age, the OR was not statistically significant.

Five other mortality studies [Dunn and Weir 1968; Puntoni et al. 1979; Polednak 1981; Becker et al. 1985; Newhouse et al. 1985] found elevated risks for lung cancer among male welders. Two of the five were cohort studies conducted on subgroups of white males who worked as welders at nuclear facilities [Polednak 1981] and at sanitary installations and power plants [Becker et al. 1985]. The larger of the two studies [Becker et al. 1985] indicated an OR of 1.7 for lung cancer that, although based on small numbers, remained increased in those workers with greater than 20 and 30 years employment. The smaller cohort study [Polednak 1981] showed elevated SMRs for the two groups of welders who were exposed and not exposed to nickel oxides. Although the welders not exposed to nickel oxides had a higher SMR, this increase could have been attributed to the higher prevalence rate (2.5 times) of smokers within the group as compared to the exposed group of welders. Two of the mortality studies [Puntoni et al. 1979; Newhouse et al. 1985] were conducted on welders in shipyards. These studies indicated elevated relative risks [Puntoni et al. 1979] and SMRs [Newhouse et al. 1985] for subgroups of welders and other occupational groups potentially exposed to welding fumes and gases. However, neither smoking habits nor the potential for exposure to asbestos were taken into consideration in these two studies. The last of the five mortality studies that showed an elevated risk of dying from lung cancer was a prospective study [Dunn and Weir 1968] that used mortality data collected from questionnaires and union records over a 5-year period. A slightly elevated OR of 1.05 was observed when adjusted for age and smoking and compared with the death rates of the total union population. No employment records were available and any potential exposures had to be derived from the questionnaires.

In a case control study [Blot et al. 1978] conducted to investigate the high rate of lung cancer among male residents of 11 Georgia coastal counties, a statistically significant increased OR of 1.6 was found for shipyard workers. However, when cases were analyzed by occupations within the shipyard, a crude OR of 0.7 was observed for welders.

An unusually high elevated risk of cancer (OR = 6.3) of the subglottic area of the larynx was found among 271 cancer patients of whom 42 had been exposed to welding fumes [Olsen et al. 1984]. The high OR persisted after adjustment for tobacco and alcohol use but was found not to be statistically significant when restricted to twelve stainless steel workers. None of the other epidemiologic studies found an elevated risk of larynx cancer.

Several of the studies that explored the relationship between exposure to welding fumes and gases and the incidence of mortality from lung cancer among welders, suffered from one or more of the following methodologic problems: (1) incomplete information on the extent of exposure, requiring estimations of these exposures from job titles, (2) insufficient cohort size and person years to observe elevated risks of lung cancer, and (3) confounding variables such as smoking and exposure to asbestos. These limitations make it difficult to draw definitive conclusions about the cause of cancer excesses observed within each study. However, collectively these studies demonstrate an elevated risk of lung cancer among welders that is not completely accounted for by smoking or asbestos exposure, and that appears to increase with the latent period from onset of first exposure and duration of employment. Additionally, a few of the studies suggest a strong association between lung cancer risk and exposures generated while welding on stainless steel. This association could be attributed to the carcinogenic properties of the nickel and chromium found in the fume.

An overview of each evaluated study is presented in Tables IV-2 through IV-4.

b. Kidney and Other Urinary Tract Cancers

The cohort mortality studies conducted by Puntoni et al. [1979], Milham [1983], and Becker et al. [1985] have shown a statistically significant increased risk of kidney or other urinary tract cancers in welders. The study by Puntoni et al. [1979] of shipyard workers showed ORs of 5.06 ($p<0.05$) and 5.88 ($p<0.05$) for cancer of the kidney and other urinary organs in gas welders when compared to the male population of Genoa, Italy and the male staff at St. Martino Hospital, respectively. Although the ORs were elevated for these cancers in electric welders, they were not statistically significant. When all shipyard workers were grouped and compared with either comparison population, the elevated ORs for these cancers were found to be statistically significant ($p<0.0005$).

Similarly, the study reported by Milham [1983] showed statistically significant ($p<0.01$) increased PMRs for kidney cancer in male welders and flamecutters who had been employed in Washington State. Welders and flamecutters analyzed during the period 1970-1979 and for the total observation period 1950-1979 had PMRs of 234 and 182, respectively.

The observations of Becker et al. [1985] were consistent with these findings with an OR of 15.0 (3 observed versus 0.2 expected) for kidney and other urinary tract cancers in welders when compared with the German national death rates. Although it was not reported by the authors, NIOSH calculated a p value of 0.002 (95% CI=3.09-43.83).

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As described earlier in this Chapter in Section B,2,a(2)(a), these three studies had a number of methodologic problems, including a lack of information on potential occupational exposures. Because of these limitations, the possible etiology for these observed cancers is difficult to assess.

c. Reproductive Effects

Adverse reproductive effects (e.g., infertility or spontaneous abortions) have been reported by Rachootin and Olsen [1983] and Lindbohm et al. [1984] for both men and women who were either employed as welders or who were potentially exposed to metals. A case-control study was conducted by Rachootin and Olsen [1983] to determine whether an association existed between delayed conception or infertility and the occupations of women and their husbands. The study population was identified from the inpatient register at a large Danish hospital; 1,069 case couples and 4,305 comparison couples were identified as study candidates. Case couples were undergoing evaluation for fertility problems, and the female partner had been admitted to the hospital for testing during the period 1977 to 1980. Comparison couples had had a healthy child born at the same hospital during the period 1977 to 1979. A questionnaire was mailed, and responses were received from 87% of each group (927 case and 3,728 comparison couples). All information on a couple was solicited from the woman. Three types of analyses were conducted.

The first analysis compared the reported occupational exposures of the case and comparison couples residing in the hospital's direct catchment area (Table IV-6). In this analysis, comparison couples were limited to those of the 3,728 comparison couples who were the parents of a healthy child conceived within 1 year. The case couples were restricted to those of the 927 case couples who were examined or treated for infertility of at least 1 year's duration. This analysis examined three subgroups of case couples: (1) those with a male partner having abnormal sperm number, motility, or shape, (2) those with a female partner having hormonal disturbances, and (3) those with idiopathic infertility. The first two subgroups had medical histories that were potentially related to occupational exposures.

The second analysis compared the reported occupational exposures of case couples (Table IV-7). The three subgroups from the first analysis were compared with infertile case couples having conditions that were unlikely to be caused directly by occupational exposures (e.g., varicocele or history of mumps as an adult in the male, or blocked fallopian tubes or endometriosis in the female).

The third analysis compared two subgroups within the original comparison group of couples who had had a healthy child born at the study hospital during the period 1977 to 1979. One subgroup was made up of comparison couples who had given birth to a healthy child after a conception delay of more than 1 year, and the second

Table IV-6.—Odds ratios and 95% confidence intervals for three subgroups of case couples compared with comparison couples, by reported occupational exposures[a]

Type of exposure	Men with sperm abnormalities		Women with hormone imbalance		Couples with idiopathic infertility			
					Women		Men	
	OR[b]	95% CI[c]	OR	95% CI	OR	95% CI	OR	95% CI
Lead, mercury, cadmium:								
Uncorrected data	0.9	0.5–1.6	0.3	0.1–1.3	2.9	1.4–6.3	0.8	0.3–1.8
Corrected data[d]	—	—	—	—	2.6	1.1–5.9	—	—
Welding of stainless steel:								
Uncorrected data	1.7	1.0–2.8	—	—	—	—	1.2	0.5–2.8
Corrected data[d]	1.7	0.9–2.9	—	—	—	—	—	—
Welding of other metals	1.0	0.7–1.4	1.2	0.3–5.0	—	—	1.4	0.9–2.3
Heat:								
Uncorrected data	1.8	1.2–2.6	1.2	0.6–2.5	1.8	0.8–4.3	1.6	0.9–2.7
Corrected data[d]	19.9	1.2–2.8	—	—	—	—	1.6	0.9–2.8
Noise:								
Uncorrected data	1.3	0.9–1.8	2.2	1.5–3.1	2.4	1.4–4.0	1.3	0.8–2.0
Corrected data[d]	1.3	0.9–1.9	2.1	1.4–3.2	2.2	1.3–3.9	—	—

[a]Adapted from Rachootin and Olsen [1983].
[b]Odds ratio.
[c]Confidence interval.
[d]Corrected for female partner's age, education, residence, and parity.

Table IV-7.—Odds ratios and confidence intervals for three subgroups of case couples compared with all other case couples, by reported occupational exposures[a,b]

Type of exposure	Men with sperm abnormalities		Women with hormone imbalance		Couples with idiopathic infertility			
					Female Partner		Male Partner	
	OR[c]	95% CI[d]	OR	95% CI	OR	95% CI	OR	95% CI
Lead, mercury, cadmium	0.9	0.5-1.8	0.4	0.1-1.4	1.9	0.7-5.2	0.7	0.3-1.7
Welding of stainless steel	1.1	0.6-2.1	0.8	0.1-13.5	—	—	0.6	0.2-1.5
Welding of other metals	0.8	0.5-1.3	1.1	0.3-5.1	0.7	0.1-2.1	1.0	0.6-1.6
Heat	1.3	0.8-2.1	0.6	0.3-1.2	0.9	0.4-2.1	0.9	0.5-1.7
Noise	1.1	0.7-1.6	0.7	0.5-1.1	0.8	0.5-1.5	0.8	0.5-1.3

[a]Adapted from Rachootin and Olsen [1983].
[b]All other case couples were those whose infertile conditions were unlikely to be related directly to occupational exposures (e.g., varicocele or mumps in the adult male or blocked fallopian tubes in the female.
[c]Odds ratio.
[d]Confidence interval.

subgroup comprised the remaining comparison couples who had conceived a healthy child within 1 year.

A variety of potentially important occupational exposures were considered in the analysis, and those relevant to the welding environment are shown in Tables IV-6, IV-7, and IV-8. In both the first analysis (Table IV-6) and the third analysis (Table IV-8), significantly elevated ORs were seen for a variety of occupational exposures associated with welding. Exposure to heat and noise was consistently associated with elevated ORs. Exposure to heavy metals and welding (either on stainless steel or other metals) was also associated with elevated ORs. Both men and women who were assigned to the exposure category "Welding of Other Metals" in the third analysis (Table IV-8) had a statistically significant increase ($p<0.05$) in delayed conception, with ORs of 1.4 (95% CI=1.1-1.8) for men and 2.4 (95% CI=1.1-5.1) for women. This risk was still statistically significant for women after adjustment for age and education, parity, area of residence, smoking habits, alcohol consumption, and past use of oral contraceptives. In contrast, men and women who were assigned to the exposure category "Welding of Stainless Steel" had no statistically significant increase in delayed conception. In the second analysis (Table IV-7), none of the exposures potentially encountered in the welding environment were associated with elevated ORs.

Lindbohm et al. [1984] evaluated possible influences of paternal or maternal occupations and exposures on spontaneous abortion by linking discharge records from Finnish hospitals with national census data. For the period 1973 to 1976, data were available for 294,309 pregnancies. Census data on occupations were used to form seven categories of presumed exposure to specific agents (animal microorganisms, solvents, polycyclic aromatic hydrocarbons, automobile exhaust fumes, other chemicals, metals, textile dust). Because the census data referred to occupations in 1975, the analysis of spontaneous abortion was limited to pregnancies in 1976. Women in these exposure categories were compared with all other "economically active" women, and wives of exposed men were compared with wives of nonexposed men. A logistic regression model was used to control for age, place of residence, parity, marital status, and age-parity interaction. None of the specific exposures were associated with a significantly increased odds ratio. The odds ratio was 0.78 (95% CI=0.54-1.13) for women exposed to metals (iron and metalware workers; smelting, metallurgic, and foundry workers; miners and quarry workers). For the wives of similarly exposed men, the OR was significantly reduced to 0.86 (95% CI=0.75-0.95).

Lindbohm et al. [1984] also used the pregnancy data for the period 1973 to 1976 to investigate spontaneous abortion by occupation. Women in five occupations had elevated ORs, but none appeared to be related to the welding environment. One of four occupations associated with increased ORs for the wives of exposed men was "metal-plate and constructional steel workers" with an OR of 1.36 (95% CI=1.00-1.85). This occupational category was not

Table IV-8.--Odds ratios and 95% confidence intervals for comparison couples who had delayed conception compared with comparison couples who conceived within 1 year, by reported occupational exposures[a]

Type of exposure	Men		Women	
	OR[b]	95% CI[c]	OR	95% CI
Lead, mercury, cadmium:				
Uncorrected data	1.3	0.9-1.8	1.7	1.1-2.8
Corrected data[d]	1.3	0.9-1.8	1.7	1.0-2.8
Welding on stainless steel	1.0	0.6-1.6	1.1	0.1-8.8
Welding of other metals:				
Uncorrected data	1.4	1.1-1.8	2.4	1.1-5.1
Corrected data	1.3	1.0-1.7	2.7	1.2-6.3
Heat:				
Uncorrected data	1.8	1.4-2.4	1.5	1.0-2.4
Corrected data	1.9	1.5-2.6	1.4	0.9-2.3
Noise:				
Uncorrected data	1.3	1.0-1.6	1.7	1.3-2.3
Corrected data	1.3	1.0-1.6	1.9	1.4-2.6

[a]Adapted from Rachootin and Olsen [1983].
[b]Odds ratio.
[c]Confidence interval.
[d]Corrected for female partner's age, education, residence, parity, smoking and drinking habits, and past use of oral contraceptives.

described in any further detail except for the comment that these men "are occasionally exposed to chromates and nickel." No information was available on smoking habits and alcohol consumption. Potential occupational exposures were assigned based on employment history.

The significance of the results from these two studies [Rachootin and Olsen 1983; Lindbohm et al. 1984] is questionable given the studies' limitations (e.g., estimation of exposures and confounding exposures of smoking or alcohol consumption).

d. Cardiovascular Effects

A few case reports indicated that exposure to welding fumes and gases may cause acute cardiac episodes or aggravate preexisting cardiovascular diseases in welders [Beintker 1932; Jacobi 1934]. In these case reports, welders worked in confined spaces with poor ventilation. No information was given as to the types of metal being welded or exposures being generated.

Two of four mortality studies cited previously in this Chapter in Section B,2,a,(2),(a) reported increased risks of cardiovascular disease in welders employed at shipyards [Puntoni et al. 1979; Newhouse et al. 1985]. Newhouse et al. [1985] observed an increased SMR of 130 (90% CI=104-156) for ischemic heart disease in welders, whereas Puntoni et al. [1979] reported ORs greater than 1.00 for a similar cohort of welders. Neither study was adjusted for smoking and no conclusions were drawn by the authors as to the relevance of the elevated risks. One of the other two mortality studies [Milham 1983] reported a PMR of 97 for welders and flame cutters when analyzed for the total study period of 1950-79; the other study [Polednak 1981] showed SMRs of 70 and 82 for welders exposed and nonexposed to nickel oxide fumes, respectively. The slightly higher SMR of the nonexposed group of welders could be attributed to the 2.5 times greater percentage of cigarette smokers reported among this group.

e. Gastrointestinal Effects

Gastrointestinal disorders in welders experiencing metal fume fever usually take the form of nausea, vomiting, and gastrointestinal cramps [Rohrs 1957; Papp 1968]. These effects appear to subside within 24 to 48 hr after acute exposure to welding fumes.

Two cases of gastrointestinal disorders were reported by Rieke [1969] in workers performing oxyacetylene torch cutting of scrap metal. Both men had been employed in a ferrous metal scrap yard where they disassembled and cut large (often painted) metal parts. The men complained of back and lower abdominal pains, poor appetite, and constipation after being exposed for several days to metal fumes. Urinary lead analysis revealed markedly elevated lead levels (e.g., 0.44 and 0.43 mg lead/liter) and both men were treated for lead intoxication and given calcium disodium edetate for several days. Following this period of treatment all gastrointestinal disorders ceased. The workers' health problems were attributed to exposure to lead contained in the paints.

In three epidemiologic studies [Mignolet 1950; Stancari and Amorati 1963; Rozera et al. 1966], an increased incidence of digestive disorders in welders was reported. Rozera et al. [1966] reported that 22% of a population of 620 welders had digestive system disorders compared with 12% found in the general industrial population. Mignolet [1950] reported similar finding among 216 welders who were placed into three groups according to the welding process they used. Thirty-five out of 85 (41%) shielded metal arc welders complained of digestive disorders, including loss of appetite, slow digestion, and nausea. Two out of 99 (2%) oxyfuel gas welders had gastric ulcers. Two out of 32 (6.3%) oxyacetylene cutters had symptoms of gastrointestinal disorders. These disorders were attributed to the inhalation of fumes from certain types (unspecified) of covered electrodes because no similar effects were noted in welders who used bare metal electrodes. Most of the symptoms associated with digestive disorders disappeared during weekends and vacations.

Gastroduodenopathies were reported by Stancari and Amorati [1963] in 264 arc welders aged 17 to 58 years. Of the 264 arc welders, 67% of those with over 10 years work experience, 43% of those with 3 to 10 years work experience, and 15% of those with less than 2 years experience had gastritis, gastroduodenitis, or gastroduodenal ulcer. The authors concluded that the inhalation of fumes and gases associated with arc welding caused the gradual development of chronic gastritis and gastroduodenitis among welders. These ulcers were described as moderate and responded well to treatment; as soon as welding was discontinued, regression occurred. The authors further stated that the specific cause of these ulcers was unknown.

Houten and Bross [1971] reported on the relative risk of cancer among male patients at a regional cancer institute. Cancer patients were compared with other admitted male patients who did not have neoplastic disease in an attempt to ascertain if specific types of cancers were associated with certain occupations. Three cases of stomach cancer were noted among welders and flamecutters, for an OR of 2.5. This cancer incidence was not statistically significant due to the small number of observed cases. In contrast, several of the mortality studies [Milham 1983; Puntoni et al. 1979; Polednak 1981; Becker et al. 1985] discussed previously in this Chapter in Section B,2,a,(2),(a) reported no increases in welder mortality as a result of cancer or other diseases of the digestive system.

f. Ophthalmologic Effects

Persons who are involved in or working near welding processes are at risk of eye injury from metal spatter and exposure to nonionizing electromagnetic radiation in the UV to IR wavelengths [NIOSH 1972a; Marshall et al. 1977]. Exposure to UV radiation from the welding arc can result in acute keratoconjunctivitis, also known as arc eye, welder's flash, or actinic ray photokeratitis. This inflammatory disorder affects the outer structure of the eye (cornea, conjunctiva, iris) and causes blurred vision, lacrimation, burning pain, and headache [NIOSH 1972a; Palmer 1983]. These symptoms usually appear within 4 to 12 hr after the beginning of the exposure and last up to 2 days. The visible radiation emitted during welding can penetrate the eye and be absorbed by the retina and choroid causing retinal injury [Palmer 1983; Marshall et al. 1977]. Similarly, exposure to the IR radiation wavelength can cause thermal damage to the cornea and aqueous humor of the eye and has been associated with the formation of lenticular cataracts [Palmer 1983].

These types of adverse ocular effects have been reported in welders who were wearing improper eye protection or no protection at all [Minton 1949; Sykowski 1951; Entwistle 1964; Karai et al. 1984]. In one study [Entwistle 1964], 31 eye injuries were reported that were caused by contact with hot slag, metal chips, sparks, and hot electrodes. Several of the injuries involved workers assisting welders, and others involved welders who had been provided with approved types of faceshields but did not use them properly. Golychev and Nikatina [1974] also reported that because eye protection was not used, cataracts occurred in a 42-year-old welder's helper who had regularly assisted electric arc welders for 19 years. This worker reportedly suffered from welder's flash and conjunctivitis 3 to 4 times a month. Other studies [Minton 1949; Sykowski 1951] have reported similar cases of retinitis and dendritic keratitis in welders who did not protect their eyes while igniting their arcs. In a case control study of 118 welders, a statistically significant ($p<0.05$) increase was observed in damage to the corneal epithelium and endothelium of the eye when compared to 85 nonwelders [Karai et al. 1984]. The increase in eye injuries was attributed to exposure to ultraviolet radiation.

Two studies [Mignolet 1950; Gupta and Singh 1968] have reported on the evaluation of visual acuity of welders. The visual acuity was evaluated in a group of 520 welders, of whom approximately 76% were under 40 years of age; 23% of the study group worked for 20 years and 20% worked up to 30 years [Gupta and Singh 1968]. Eye complaints that included watering, blurred vision, burning, soreness, and haziness were reported by 60% of the welders. The principal clinical conditions, reported in descending order of frequency, were conjunctivitis (45%), keratoconjunctivitis (11%), pterygium (7%), incipient cataract (7%), edema of the lids (5%), brown pigmentation around the cornea (4%), trachoma (2%), corneal opacity (2%), and dilated pupils (2%). The two most common eye injuries were imbedded foreign bodies in the eye (21%) and burns of the conjunctiva (4%). Almost all the welders had suffered from arc flash at least once. Visual acuity in 33% of the welders was at the minimum accepted acuity for welders (20/30). Serious visual impairment was observed in 20%; substandard acuity of 20/60 or less was present in 59% of the welders; and defective muscle balance of the eyes was noted in 78%. The percentage of welders with defective visual performance increased with age. A similar investigation of visual acuity was made in a group of 216 welders [Mignolet 1950]. Although the types of tests conducted were not stated, unilateral and bilateral alterations in visual acuity were reported for 41% of the oxyfuel gas welders, 47% of the oxyacetylene cutters, and 58% of the arc welders. Two cases of cataracts were also noted. No control groups were used in either study for comparison of visual acuity.

g. Dermatologic Effects

Dermal effects related to welding processes may result from exposure to UV radiation [Grimm and Kusnetz 1962; Pattee et al. 1973; Balabanow et al. 1967; Roquet-Doffiny et al. 1977; Ross 1978] and IR radiation [Lydahl 1984; Moss et al. 1985], from hot metal spatter [Britton and Walsh 1940; Entwistle 1964; CDLSR 1975], and from sensitization to metals [Kaplan and Zeligman 1963; Fregert and Ovrum 1963; Shelley 1964; Kalliomaki et al. 1977].

Exposure of the welder's skin to UV radiation can result in skin burns similar to sunburn. According to a review by Pattee et al. [1973], the most common sites for such burns are the arms, hands, neck, and chin. Ross [1978] also noted that the front and sides of the neck were the most common sites for such burns. In a clinical investigation conducted by Dreesen et al. [1947], 25% of 3,255 arc welders had burns or scars from burns on their bodies. Similar findings were noted by Entwistle [1964] who reported that over 50 cases of burned fingers, wrists, hands, elbows, arms, and legs occurred among welders during an 8-month period. The cause of those burns was attributed to metal spatter, hot slag, and the flame from oxyacetylene torches. Several case reports have documented the occurrence of chronic dermatitis among welders and other persons working near welding processes [Shelley 1964; Balabanow et al. 1967; Roquet-Doffiny et al. 1977]. Balabanow et al. [1967] reported a case of dermatitis in a welder who had been in this occupation for 35 years. He suffered from edema of the eyelids and redness of the face and neck, the scalp, upper chest, back of hands, forearms, and the lower extremities. A series of clinical tests revealed no pathologic cause for these effects other than welding. A similar finding was reported by Shelley [1964] for a 40-year-old crane operator who worked near welding operations and had had recurrent eczematous eruptions on both hands for 14 years. Roquet-Doffiny et al. [1977] reported a severe case of chronic actinic dermatitis, erythema, atrophic plaques, telangiectasis, and pruritic keratotic lesions for a welder who had been performing oxyacetylene gas welding for 30 years. In addition, over a 4-year period, eight tumors were removed from his face and neck--five basal cell carcinomas and three squamous cell carcinomas. Exposure to radiation and welding fumes and gases was reported in all three reports as the causative factor in the observed skin diseases. When workers discontinued welding or were removed from the work environment where welding was being performed, dermatitis ceased.

Among welders, a number of cases involving chromium skin sensitization have been reported [Fregert and Ovrum 1963; Kalliomaki et al.1977]. Kalliomaki et al. [1977] reported a case of chromium sensitivity involving dermal allergy and asthma for a welder who typically welded on stainless steel. After the individual welded on stainless steel for about 1 hr, bronchial obstruction was observed that, according to the investigator, demonstrated severe sensitivity to the fume exposure. Measurements of airborne hexavalent chromium revealed concentrations of 0.02 to 1.7 mg/m^3. A similar finding was reported by Fregert and Ovrum [1963] for a welder who experienced repeated episodes of facial contact dermatitis while welding. The welder was found to be sensitized to chromium that was emitted while he welded on stainless steel or from the welding rod that contained trace amounts of chromium. The dermatitis disappeared after the welder ceased his exposure to welding fumes that contained chromium.

h. Auditory Effects

Hearing loss among welders has usually been due to traumatic injury [Frenkiel and Alberti 1977] or to excessive sound pressure [Hickish and Challen 1963; Bell 1976]. Frenkiel and Alberti [1977] reviewed 11 cases of middle ear trauma resulting from burns, including 5 such cases in welders. The eardrums of the welders were perforated by flying sparks or pieces of metal during welding processes. In four of the five cases, hearing loss was permanent. Auditory impairment from exposure to excessive noise levels may occur during arc air gouging of metal, and plasma torch processes [Hickish and Challen 1963; Bell 1976]. Bell [1976] reported that a considerable risk of noise-induced deafness was possible among a group of welders during arc air gouging in which sound level measurements exceeded 115 dbA. Hickish and Challen [1963] noted a mean temporary hearing loss in both ears of 19 dB at 4,000 Hz and up to 35 dB at 8,000 Hz in three persons who were exposed to the noise from a plasma torch for 1 hr. In one person, recovery of normal hearing took 48 hr.

i. Musculoskeletal Effects

Welding is a static type of work that usually requires customary postures and considerable shoulder joint motion. Shoulder pain may be caused or aggravated by welding. Complaints of shoulder pain are very common among older welders, according to observations by Herberts and Kadefors [1976], who investigated the clinical and radiological features of shoulder pain in 10 shipyard welders aged 50 to 65 years. An electromyographic (EMG) evaluation of the impact of static loading on their shoulder muscles was also conducted. The most consistent finding was reduced muscle power and shoulder pain. All subjects had normal shoulders upon inspection, but mild local tenderness of the rotator cuff was always present. Measurement of the isometric muscle power revealed reduced power in the painful shoulder in abduction, outward rotation, and flexion. The radiographic appearance was normal in only 3 of the 10 subjects. Analysis of EMG signals recorded during actual overhead welding revealed significant changes in the action potential of the supraspinatus muscle, implying that this muscle is under sustained heavy strain in this working situation.

Kadefors et al. [1976] also studied the effect of overhead welding on muscles of the shoulder in 20 welders aged 20 to 35 years. An inexperienced group consisted of 10 men with less than 1 year of welding experience, and the experienced group consisted of 10 men who had been working for more than 1 but less than 5 years. Among the inexperienced workers, overhead welding resulted in EMG changes indicative of localized fatigue in the deltoid, upper trapezius, and supraspinatus muscles. Experienced welders demonstrated some adaptation but still had abnormal EMG readings for the supraspinatus muscles. The authors concluded that overhead welding places considerable amounts of strain on this muscle, which cannot be overcome by experience and training.

Petersen et al. [1977] reported similar findings in a third study. Those observed included 10 experienced workers with at least 5 years of experience and 10 inexperienced welders with less than 1 year of training. After overhead welding, all experienced welders and a few inexperienced welders (number not given) showed increased fatigue of the supraspinatus muscle. A subset of older welders complaining of shoulder pain was tested further. Clinical examination (X-ray) showed diminished strength in shoulder movements in which the supraspinatus was active, and clear signs of supraspinatus tendinitis. However, it was emphasized that the tendinitis may have been caused by long exposure or as a consequence of natural changes from age in combination with overhead welding.

Ross [1978] reported on the results of medical examinations of 926 shielded metal arc welders; all were male, had heavy engineering and shipbuilding experience, and had been observed for 6 years. These findings were compared with the results of medical examinations of 755 nonwelders who were used as controls. Chronic conditions encountered included occupational hearing loss, Raynaud's phenomenon, and Dupuytren's contracture. Raynaud's phenomenon, also called white finger disease, affected 102 (11%) of the welders, compared with 7 (1%) of the nonwelders. It was associated with the use of vibratory tools but was considered by the author to be relatively minor in nature. Dupuytren's contracture, a flexion deformity of the finger, which the author reported as not usually occupational in origin, was found in 38 (4%) of the welders and 4 (0.5%) of the controls. The author speculated that it could be caused by tightly gripping the electrode holders.

Nauwald [1980] studied knee joint changes in 100 welders (type not stated) in the shipbuilding industry. Sixty-nine of the 100 welders complained of spontaneous pains in the knee joints. These included pain during motion, pain when starting to move, pain during hypercompression of the joint, and the so-called "giving-away" phenomenon. Arthritis, proliferation of fatty tissue in knee joint, and fluid sac diseases were observed with increasing frequency in welders who were older than 25 and had a minimum exposure time of 6 years. The author stated several potential causative factors in the development of the observed knee joint diseases: (1) the static-mechanical stress on the bent knee while working, (2) the chronic, persistent pressure on the soft parts of the joint, and (3) thermal effects such as cooling due to kneeling on cold iron for an extended period of time.

C. Safety Hazards

In addition to being exposed to chemical and physical agents, welders are also exposed to potential safety hazards that may result in injury or death. Most of the injuries occur as a result of poor work practices, inadequate engineering controls, or improper or inadequate training.

Work injury data were obtained from the Supplementary Data System (SDS) of the Bureau of Labor Statistics (BLS) occupational code 680 (welders and flame cutters) for 1976-81 [BLS 1985]. In a cross analysis, the source of injury was cross-tabulated with type of accident, nature of injury, and body part. The analysis of the SDS accident/injury data was performed for the top 10 source-of-injury categories that identified tools, tasks, or equipment used by welders and thermal cutters. A total of 166,907 injuries were reported to the SDS data base from welders and thermal cutters during the period 1976-1981; 109,774 of these injuries were included in the cross analysis and reported in Table IV-9. The SDS data do not include any information on the cause of the injury.

The Bureau of Labor Statistics [1983] obtained data from 18 States on welding- and cutting-related injuries for 1,364 workers that occurred during a 5-month period in 1978. Forty-two percent of the reported injuries during this period occurred in welders or cutters who had 5 or more years of experience; 92% of these welders and cutters had received safety training in the form of classroom or on-the-job safety training or written material about welding or cutting safety measures. Arc welding or cutting was being performed when two-thirds of these injuries occurred, and 83% had received safety training in the use of this equipment. Sixty-seven percent of the reported injuries were to the eye(s); 58% of the burns to the eyes resulted from welding being performed in the nearby work area; 50% of all eye injuries occurred as a result of not wearing filtering lenses to protect the eyes.

Injury of workers by industrial welding robots has also occurred. Specific types and the number of injuries reported for welders involved in these types of processes are not available; however, this kind of information is being gathered by the Division of Safety Research, NIOSH [NIOSH 1985]. According to Percival [1984], the six main sources of hazards from industrial robots are as follows: (1) control errors caused by errors in the software, faults within the control system, or electrical interference; (2) unauthorized access to robot enclosures; (3) human error when working close to a robot; (4) electrical, hydraulic, and pneumatic faults; (5) mechanical hazards from the function of the robot (e.g., welding hazards); and (6) environmental hazards (e.g., dust, fumes, radiation). Although specific controls for these hazards are not addressed in this

Table IV-9.--Summary of SDS accident/injury profile, 1976-1981, for welders and thermal cutters (occupational code 680)[a]

Source of injury	Total number of accidents/ injuries	Accidents		Injuries		Body part injured	
		Type	Number[b]	Type	Number[b]	Body part	Number of injuries[b]
Welding equipment, electric arc	11,261	Contact with radiation, caustics, etc., NEC[c]	6,129	Welder's flash	9,517	Eye	10,463
		By absorption	3,528	Radiation effects	884	Finger	144
		Accident type, NEC	498	Burn or scald	295		
		Contact with hot objects or substances	299				
		Contact with electric current	241				
Particles (unidentified)	9,080	Rubbed or abraded by foreign matter in eyes	7,583	Scratch, abrasion	7,853	Eye	8,931
		Struck by flying object	748	Other injury, NEC	778		
		Struck by NEC	261				
Metal items, NEC	7,857	Struck by NEC	1,204	Scratch, abrasion	1,825	Eye	2,608
		Rubbed or abraded by foreign matter in eyes	1,180	Cut, laceration, puncture	1,385	Finger	1,096
		Struck by falling object	1,103	Sprain, strain	1,339	Back	941
		Overexertion in lifting objects	956	Contusion	973	Foot (not toes)	510
		Struck against stationary object	706	Burn or scald	653		
Bodily motion	7,365	Bodily reaction	3,040	Sprain, strain	6,338	Back	3,126
		Bodily reaction by voluntary motions	2,158	Dislocation	222	Knee	1,282
		Bodily reaction by involuntary motions	1,844	Inflammation or irritation of joints, tendons, or muscles	214	Ankle	989
		Rubbed or abraded by repetition of pressure	98	Nonclassifiable	158	Neck	224

(Continued)

See footnotes at end of table.

Table IV-9 (Continued).—Summary of SDS accident/injury profile, 1976-1981, for welders and thermal cutters (occupational code 680)[a]

Source of injury	Total number of accidents/ injuries	Accidents: Type	Accidents: Number[b]	Injuries: Type	Injuries: Number[b]	Body part injured: Body part	Body part injured: Number of injuries[b]
Floor (of a building, a scaffold, a mine, a vehicle, etc.)	5,172	Fall to the walkway or work surface	2,439	Sprain, strain	2,128	Back	1,022
		Fall on same level, NEC	924	Contusion, crushing, bruise	1,021	Knee	818
		Fall from ladder	611	Fracture	826	Multiple parts	615
		Fall from scaffold, walkway, platform, etc.	264	Nonclassifiable	441	Ankle	443
Beams, bars	4,820	Struck by falling object	1,338	Sprain, strain	1,638	Back	1,139
		Overexertion in lifting objects	1,049	Contusion, crushing, bruise	1,119	Finger	726
		Struck by NEC	561	Fracture	832	Foot (not toes)	486
		Struck against stationary object	486	Cut, laceration, puncture	519	Toe	346
		Caught in, under, or between a moving and a stationary object	220				
Nonclassifiable	4,770	Nonclassifiable	2,432	Sprain, strain	1,547	Back	1,142
		Overexertion in lifting objects	611	Nonclassifiable	946	Eye	552
		Rubbed or abraded by foreign matter in eyes	213	Contusion, crushing, bruise	379	Finger	398
				Cut, laceration, puncture	394	Abdomen	240
				Nonclassifiable	316		

(Continued)

See footnotes at end of table.

Table IV-9 (Continued).--Summary of SDS accident/injury profile, 1976-1981, for welders and thermal cutters (occupational code 680)[a]

Source of injury	Total number of accidents/ injuries	Accidents		Injuries		Body part injured	
		Type	Number[b]	Type	Number[b]	Body part	Number of injuries[b]
Pipe	3,957	Struck by falling object	962	Sprain, strain	1,421	Back	989
		Overexertion in lifting objects	909	Contusion, crushing, bruise	857	Finger	603
		Struck by NEC	451	Fracture	519	Foot (not toes)	486
		Struck against stationary object	364	Cut, laceration, puncture	488	Toe	346
		Caught in, under, or between a moving and a stationary object	174				
Miscellaneous, NEC	3,666	Overexertion in lifting objects	895	Sprain, strain	1,385	Back	939
		Struck by falling objects	512	Contusion, crushing, bruise	644	Finger	557
		Overexertion in pulling or pushing objects	212	Cut, laceration, puncture	437	Foot (not toes)	206
		Caught in, under, or between NEC	200	Fracture	289	Eye	203
Flame, fire, smoke	3,479	Contact with hot objects or substances	2,960	Burn or scald (heat)	3,073	Hand	482
		Contact with radiation, caustics, toxic and noxious substances	206	Other injury, NEC	52	Multiple parts	474
		Explosion	91	Influenza, pneumonia, bronchitis, asthma, pneumonitis, emphysema	44	Eye	314
						Finger	255

[a]Source: BLS [1985].
[b]These figures include only those for the most frequent subcategories of each major heading ("Accidents," "Injuries," or "Body part injured"); thus their totals do not match those under "Total number of accidents/injuries.
[c]Not lsewhere classified.

document, many of the measures recommended for controlling emissions generated at other welding processes can be applied to industrial welding robot operations.

Some of the specific safety hazards associated with welding processes are fires, explosions, or electric shocks. The following are case reports of injuries and fatalities resulting from such hazards.

1. Fires

The fire hazards caused by either the welding flame itself or flying sparks have been responsible for injuries and fatalities of workers [NFPA 1977; Buhrer and Brunschwiler 1978]. Fires associated with oxygen-enriched atmospheres provide dramatic examples of the risks involved when there is either enrichment of the air by oxygen in enclosed spaces or leakage of oxygen. Accidents have also been reported when air has been intentionally enriched (sweetened) before welding to purge the air of contaminants.

Three fires in oxygen-enriched atmospheres were reported by Rames [1976]. The first occurred inside a storage tank where a welder was making repairs by electric arc welding. He enriched the inside atmosphere with oxygen from a cylinder outside the tank. His assistant went inside to help instead of keeping watch outside. After 20 min, their clothing suddenly ignited, and although they succeeded in getting out of the tank, they both died on the way to the hospital. The second case report was of a welder who went down a deep well to cut a rusty suction basket from a pump. Before he descended, he fed oxygen instead of compressed air into the well because he thought there might be dangerous gases present. When he started to cut, his clothing burst into flames and he fell into the water. His assistant, who was watching, was unable to help. The welder was dead when he was removed from the well. The third case was that of a welder and his assistant who were arc welding while repairing pipelines inside a small channel. Their clothing suddenly caught fire, and even though they were being observed from the outside by others, they died before they could be rescued. Investigation of the accident revealed that they were using oxygen from the cutting equipment to sweeten the air.

The National Fire Protection Association (NFPA) [NFPA 1977] reviewed reports of several fires caused by cutting and welding equipment. During repairs of an underground missile silo, a welder struck and caused a rupture to a temporarily installed, high pressure hose containing hydraulic oil. The oil escaped as a fine mist and ignited at the electric arc. Although the fire was of short duration, it killed 53 of the construction workers trapped in the confined silo space.

The California Division of Labor Statistics and Research (CDLSR) [CDLSR 1975] also described several fires resulting from welding. An auto dismantler was using an acetylene torch to cut the metal straps holding a fuel tank in place. The tank fell to the ground and pulled off the filler spout. Sparks from the torch ignited the fuel in the tank. The dismantler sustained second-degree burns on his hands and face. In another occurrence, a man was burning and cutting scrap metal. The oxygen hose caught fire and caused the worker to drop the torch, breaking the fitting. Oxygen went up his pants leg, which ignited. In another incident, a ladle helper was holding an oxygen hose while another worker was cutting with a torch. The oxygen accumulated in the worker's glove, ignited the glove, and burned his right hand.

2. Explosions

Explosions caused by welding sparks igniting flammable or explosive materials are a potential problem associated with all welding processes. A mixture of acetylene with air containing more than 2.5% or less than 80% acetylene is explosive [Compressed Gas Association 1966].

Fire resulting from an explosion occurred in the cooling plant located in the basement of a newly erected hospital [Buhrer and Brunschwiler 1978]. A chief electrician and an electrical fitter were installing wiring for an electrical plant. The chief electrician who had on-the-job experience had not received any formal welding training. While cable supports were being welded from a ladder, sparks fell to the floor igniting a rag lying on a varnish can. An explosion occurred and both workers were immediately surrounded by flames. The welder on the ladder was able to escape. His coworker who was unable to escape suffered extensive burns.

The NFPA [1977] described several explosions caused by welding that resulted in death. In one case, a workman using a torch to cut an object on the top of a drum containing kerosene cut into the drum and the oil exploded, fatally burning him. In another case, after partially unloading a tanker of asphalt stored at a temperature of about 143°C (290°F), two workmen went to the top of the tank to straighten the pipe through which they measured the oil level. They were using an acetylene torch that ignited the leaking vapors and caused an explosion that killed both men. In another reported incident, three welders were killed as a result of an explosion that occurred while they were repairing a leak in an odor-scrubbing system. Heat from the torch had ignited flammable vapors within a connecting pipe, and the flame was propagated to the tank that contained naphthalene. The tank ruptured, killing all three workmen.

Several explosions were reported in the CDLSR description of welding accidents [CDLSR 1975]. Some of these occurred in atmospheres enriched by oxygen and some occurred when sparks caused the ignition of flammable vapors or liquids that had leaked from hoses or containers.

3. Electric Shocks

Because currents of 100 to 600 A at 30 to 60 V, either AC or DC, are used in welding, shocks to workers have resulted in falls causing serious injuries or deaths [Britton and Walsh 1940]. The usual practice in welding operations is to have the work grounded to one terminal of the power supply while the electrode holder is connected to the other terminal. Fatalities have resulted from a current passing through the body when the worker stepped on the "live" electrode, while in contact with the other terminal of the current. Careless handling or changing of electrodes has also resulted in serious injuries and fatalities.

Five welding-related deaths from electrocution occurring between 1956 and 1975 were reported by Simonsen and Petersen [1977]. One case involved a 37-year-old electric arc welder who was working in a confined space where the temperature was 35° to 40°C (95° to 104°F). He had perspired heavily and had removed one glove. The welder developed severe spasms, apparently from an electrical contact, was hospitalized, and died a short time later. Burnlike lesions were found on his lower right cheek, left thigh, and left hand.

Another welder was presumably attempting to ignite his cutting torch by drawing a spark from the welding apparatus while the transformer was operating. He suddenly fell and died a short time later. The authors provided no information on the type of protective clothing worn. Electrical malfunction of the welding machine was not a factor in this fatality.

In a third reported fatality, a 22-year-old man was welding a metal plate onto the hull of a ship while standing on a platform located about 50 cm above the water surface. He had been working for 4 hr when he lay down to weld on the edge of the plate. A large wave immersed the platform, and the welder's hand holding the welding device was submerged in water. He died from electric shock.

In 1974, a 47-year-old welder was found dead at his workplace. He had been welding on the floor of a small compartment that measured 70 x 73 x 105 cm. There was a small amount of water on the floor of the compartment. When he was found, the welding tool was in his right hand and the end of the welding electrode had slid under the face mask and up under his glasses near the left eye. At autopsy, a burnlike perforation of the median sclera of the left eye was found. In 1975, a 47-year-old man was found dead in a section of a ship where he had been welding. He was found lying on his back against the side of the ship with the welding tool in his left hand and the tip of the electrode pointing toward his throat. His helmet and mask lay beside him. It was very hot in the area where he had been working, and his clothing was soaked with perspiration. The authors stated that the welding apparatus was not defective and the maximum voltage at idle was 86.0 V. The autopsy revealed an electrical burn on the right side of the throat.

V. BASIS FOR THE STANDARD

A. Introduction

This chapter summarizes the studies used by NIOSH to form the basis of its recommended standard for welding, brazing, and thermal cutting. NIOSH believes that the studies discussed here provide the best available evidence of the association between adverse health effects and welding. The results of these studies are summarized briefly in the following subsection; they are described and fully referenced later in the chapter.

B. Summary

Analysis of data obtained from welders reveals several types of adverse effects associated with various welding processes. The respiratory system is the primary target of injury. Metal fume fever and pneumonitis are the most common acute respiratory diseases associated with welding as a result of short-term exposures to high concentrations of fumes and gases. Chronic respiratory diseases such as cancer, pneumoconiosis, and bronchitis have been observed among welders exposed to welding fumes and gases (and possibly to asbestos in some instances over long periods). In addition to respiratory diseases, cancers of the kidney, and other urinary tract organs, and the subglottic area of the larynx have been described in such workers. Other health effects and injuries reported include cardiovascular and gastrointestinal diseases, skin sensitization, hearing loss, and eye and musculoskeletal injury. Some evidence indicates a possible relationship between adverse reproductive outcomes and exposure to welding fumes. Because of the diversity of welding techniques, processes, and materials used, most of these studies lack sufficient information to associate a specific chemical or physical agent with a particular health effect.

C. Malignant Diseases

1. Lung Cancer--Epidemiologic Studies

a. Exposure to Fumes from Welding on Stainless Steel and Other Metal Alloys

Statistically significant increases in the rates of lung cancer have occurred among welders exposed to fumes and gases generated from welding on stainless steel [Sjogren 1980; Gerin et al. 1984; Sjogren et al. 1987] and other metal alloys [Breslow et al. 1954; HMSO 1978; Beaumont and Weiss 1981; Milham 1983; Steenland et al. 1986; Schoenberg et al. 1987]. In four of these studies, exposure-response relationships were demonstrated [Sjogren 1980; Beaumont and Weiss 1981; Gerin et al. 1984; Schoenberg et al. 1987].

Steenland et al. [1986] and Sjogren et al. [1987] reaffirmed the excess lung cancer risk when they reanalyzed the studies by Beaumont and Weiss [1981] and Sjogren [1980], respectively.

Beaumont and Weiss [1981] reported excess cancer rates that increased with the duration of welding exposure and the length of time from onset of first exposure. A standard mortality ratio (SMR) of 132 ($p=0.06$) was observed for deaths from lung cancer among welders compared with those for U.S. white males. The SMR for deaths from lung cancer was 174 ($p<0.001$) when calculated on the basis of deaths that occurred 20 or more years after first welding exposure or initial employment as a welder. This study cohort was reanalyzed by Steenland et al. [1986] using an internal comparison group who more closely matched the lifestyles (e.g., smoking habits) of the welders and who were potentially exposed to the same occupational hazards (e.g., asbestos). The lung cancer risk remained statistically significant, with an OR of 152 ($p=0.03$) when duration of exposure was measured using the year the worker was first employed as a welder. An OR of 1.29 ($p=0.03$) for lung cancer was also observed for welders as a function of increasing cumulative exposure.

Two studies [Sjogren 1980; Gerin et al. 1984] reported increased incidences of lung cancer among welders who were exposed to stainless steel welding fumes that contained nickel and chromium. Sjogren [1980] reported an OR of 4.4 ($p<0.03$), and Gerin et al. [1984] found an OR of 3.3 (95% CI=1.2 to 9.2) among another group of stainless steel welders. Deaths from lung cancer remained statistically significant in both studies after adjustment for smoking habits. Although no exposure data were available for either study, measurements of airborne chromium were taken by Sjogren [1980] at similar stainless steel welding sites. They revealed median TWA chromium (trivalent and hexavalent) concentrations of 210 g/m^3 during welding with covered electrodes and 20 $\mu g/m^3$ during gas-shielded welding.

Sjogren et al. [1987] reported on a reanalysis of these stainless steel welders [Sjogren 1980] to determine lung cancer risk after 7 years of additional followup. The lung cancer risk remained high for the stainless steel welders, who had an SMR of 249 when their death rates were compared with national death rates. This cohort was also compared with another group of welders who did not weld on stainless steel but were exposed to low concentrations of chromium. These welders had a relative risk of 7.01 (95% CI=1.32 to 37.3) for lung cancer compared with stainless steel welders, which suggests that emissions typically produced during the welding of stainless steel (e.g., chromium, nickel) may be associated with excess lung cancer risk.

b. Exposure to Welding Fumes in General

Studies reported by Breslow et al. [1954], HMSO [1978], Milham [1983], and Schoenberg et al. [1987], provide evidence of an association between exposure to various compositions of welding fumes and gases and an increased risk of lung cancer. A statistically significant ($p<0.05$) OR of 1.56 was reported by Breslow et al. [1954] in a case control study of 518 lung cancer patients that included 10 welders and 4 sheet metal workers exposed to welding fumes. The OR remained statistically significant after adjustment for smoking habits.

Milham [1983] reported on the proportional mortality of lung cancer among welders and flame cutters employed in the State of Washington. The study used death certificates collected over a 29-year period; proportional mortality ratios (PMRs) were determined at 10-year intervals. A statistically significant ($p<0.01$) PMR of 136 was observed for the period 1970-79, and a PMR of 135 ($p<0.01$) was observed for the total study period (1950-79). In another study [HMSO 1978], statistically significant ($p<0.01$) SMRs of 151 (not controlled for smoking) and of 116 (controlled for smoking) were found for a group of workers classified as "gas and electric welders, cutters, and braziers." The study cohort was made up of workers employed in different industries and potentially exposed to various compositions of fumes and gases.

A study of welders in the Louisiana petroleum industry also showed a statistically significant lung cancer risk [Gottlieb 1980]. However, when the cohort was adjusted for age, the OR was no longer statistically significant.

Although an increased risk of lung cancer was found for welders in these studies [Breslow et al. 1954; HMSO 1978; Gottlieb 1980; Milham 1983], the absence of specific exposure information, type of welding performed, and possible concomitant exposures (e.g., asbestos) makes it difficult to associate exposure with the risk of lung cancer. However, in a case control study reported by Schoenberg et al. [1987], shipyard welders had a statistically significant increase in the rate of lung cancer, with an OR of 3.8 (95% CI=1.8 to 7.8). This risk remained high after adjustment for smoking and exposure to asbestos. Of the 33 cases and 18 controls classified as welders, 16 cases and 7 controls were reported to have been exposed to asbestos. The remaining 17 cases and 11 controls who had no reported asbestos exposure, showed an increased smoking-adjusted OR of 2.5 (95% CI=1.1 to 5.5).

Four other mortality studies [Puntoni et al. 1979; Polednak 1981; Becker et al. 1985; Newhouse et al. 1985] reported increased risks for lung cancer among male welders. Although the increases were not statistically significant, the studies collectively demonstrate the possible association between classification as a welder and an increased risk of developing lung cancer. Two of the four studies were conducted on white males who worked as welders at nuclear facilities [Polednak 1981] or at sanitary installations and power plants [Becker et al. 1985].

The larger of those studies [Becker et al. 1985] revealed an OR of 2.4 ($p<0.05$) for all cancers and an elevated OR of 1.7 ($p>0.05$) for cancer of the trachea, bronchus, and lung when compared with a control group that was not exposed to welding fumes. When an external analysis was performed (i.e., comparison with the German national death rates), SMRs for deaths from malignant neoplasms and lung cancer were not markedly increased over the general population. However, when welders were analyzed by 10-year intervals since first exposure, an upward trend in SMRs was observed. The incidence of malignant neoplasms was statistically significant ($p<0.05$) only for the last interval ($\geq$ 30 years since first exposure).

In the smaller cohort study [Polednak 1981], welders were analyzed according to their potential exposure to nickel oxides. Increased SMRs were observed for lung cancer deaths among both exposed (SMR=124) and unexposed (SMR=175) welders. The SMRs were not statistically significant when compared with death rates for U.S. white males. The welders who were not exposed to nickel oxides had a prevalence of smoking that was 2.5 times that of the exposed group. The difference in smoking habits and the fact that the study groups were small (N=536 exposed, N=523 unexposed) contribute to uncertainty in the interpretation of the results. Although the SMRs did not reach statistical significance, the risk of death from lung cancer increased among both groups of welders with increasing years of exposure to welding fumes and gases.

Studies of welders in shipyards [Puntoni et al. 1979; Newhouse et al. 1985] demonstrate an increased risk of lung cancer. Although neither study showed statistically significant increases, Puntoni et al. [1979] found elevated ORs for lung cancer in gas welders (OR=2.12) and electric welders (OR=2.54) when compared with the male staff of a local hospital. An elevated OR of 1.25 for gas welders and an OR of 1.60 for electric welders were observed when the groups were compared with the male population of Genoa, Italy.

Newhouse et al. [1985] found an elevated SMR of 113 for deaths from lung cancer among a group of welders who performed various welding tasks during ship repair. Latency and duration of employment were not analyzed in either study, and no attempt was made to account for the confounding exposure of asbestos.

2. Other Cancer--Epidemiologic Studies

Several studies indicate a possible association between classification as a welder and an increased risk of cancer of the larynx [Olsen et al. 1984] and of the kidney or other urinary tract organs [Puntoni et al. 1979; Milham 1983; Becker et al. 1985]. Skin cancer has also been reported among welders employed for more than 30 years in this occupation [Roquet-Doffiny et al. 1977].

A case-control study conducted by Olsen et al. [1984] reported an unusually high risk of cancer (OR=6.3) of the subglottic area of the larynx among 271 cancer patients who had been occupationally exposed to welding fumes and gases. The high OR for this type of cancer persisted after adjustment for tobacco and alcohol use, but it was not high for those patients (N=12) reported to have been exposed to fumes from stainless steel welding. Other epidemiologic studies [Dunn and Weir 1968; Ott et al. 1976; HMSO 1978; Puntoni et al. 1979; Sjogren 1980; Polednak 1981; Milham 1983] revealed no elevated risk of larynx cancer.

Several cohort mortality studies [Puntoni et al. 1979; Milham 1983; Becker et al. 1985] have reported increased incidences of kidney or other urinary tract cancers among welders. The study of shipyard workers by Puntoni et al. [1979] reported ORs of 5.06 ($p<0.05$) and 5.88 ($p<0.05$) for cancer of the kidney and other urinary tract organs in gas welders compared with two different external control populations. Elevated but statistically insignificant ORs were also reported for electric arc welders. An increased risk of kidney cancer was also noted by Milham [1983] in welders and flame cutters (PMR=182, $p<0.01$), and Becker et al. [1985] reported a statistically significant ($p<0.002$) OR of 15.0 (3 observed versus 0.2 expected) for kidney and other urinary tract cancers among welders. No exposure data were reported in any of the three studies, but Becker et al. [1985] reported that most of the welders in his study performed arc welding with coated chromium-nickel alloy electrodes. Although these studies associated classification as a welder with an increased risk of dying from kidney or other urinary tract cancers, other mortality studies [Dunn and Weir 1968; Ott et al. 1976; HMSO 1978; Polednak 1981; Newhouse et al. 1985] indicated no increased incidences of death from these causes.

3. Toxicological Evidence

The risk of cancer noted among welders is consistent with the findings of in vitro and in vivo mutagenesis assays that have demonstrated various mutagenic potentials for welding fumes, depending on their composition [Hedenstedt et al. 1977; Koshi 1979; Stern et al. 1982; Pedersen et al. 1983]. Results of assays have shown that most of the mutagenic activity of stainless steel welding fumes can be ascribed to chromium(VI) in the water-soluble fraction [Stern et al. 1982]. Maxild et al. [1978] reported that shielded metal arc welding of stainless steel produces 3 to 6 times more fumes (per mass of weld metal) than gas metal arc welding. When the mutagenic potentials for shielded metal and gas metal arc fumes were compared on an equivalent chromium(VI) basis, gas metal arc welding fumes produced four times more mutations in bacteria than shielded metal arc welding fumes [Stern et al. 1982]. Other data reported by Hedenstedt et al. [1977] and Stern et al. [1982] suggest that compounds other than chromium(VI) may be active in the water-soluble fractions of fumes generated from shielded or gas metal arc welding of stainless steel. When water-soluble fractions of both fumes were tested in an assay using metabolically activated <u>S. typhimurium</u>, arc welding fumes were less mutagenic.

In a 2-year study reported by Reuzel et al. [1986], evidence of carcinogenicity was found in animals exposed to stainless steel fumes. Syrian golden hamsters were intratracheally injected with saline suspensions of stainless steel fumes from shielded metal arc welding. One lung cancer resulted from each of two dose groups. No cancers were observed in the untreated control groups or in animals treated with gas metal arc fumes, calcium chromate (positive control), or saline. Because these tumors are extremely rare in Syrian golden hamsters, the authors concluded that the lung tumors were induced by welding fumes.

D. Other Diseases

1. Acute Respiratory Diseases

a. Epidemiological Studies

One of the more frequently reported health effects from exposure to welding fumes is metal fume fever, which often resembles an upper respiratory infection such as influenza, acute bronchitis, pneumonia, or upper gastrointestinal infections [Papp 1968]. These conditions usually last 6 to 24 hr and are often accompanied by chills, trembling, nausea, and vomiting [Rohrs 1957]. Exposure to specific metals such as zinc in zinc oxide fumes [Drinker 1922; Drinker et al. 1927] and to fumes of mixed composition [Ross 1974; Johnson and Kilburn 1983] have been associated with metal fume fever. Although no specific exposure concentrations have been associated with metal fume fever, most reported cases have occurred in workers exposed to welding fumes while working in confined or other poorly ventilated spaces.

Pneumonitis and pulmonary edema have been reported in welders who performed various welding processes (e.g., gas and shielded metal arc welding, silver brazing, or oxyacetylene welding) and were exposed over short periods to high concentrations of nitrogen dioxide [Maddock 1970; Mangold and Beckett 1971], ozone [Molos and Collin 1957; Kleinfeld et al. 1957; Challen et al. 1958], cadmium fumes [Patwardhan and Finckh 1976; Blejer and Caplan 1969; Townshend 1968], chromium and nickel fumes [Jindrichova 1976], or aluminum and iron oxide fumes [Herbert et al. 1982]. Cases of acute cadmium fume pneumonitis and death have been reported among welders exposed either by brazing with silver-cadmium alloy or by cutting or welding cadmium-coated metal in poorly ventilated areas [Christensen and Olson 1957; Beton et al. 1966; Patwardhan and Finckh 1976]. Beton et al. [1966] reported on the death of a welder who was cutting cadmium-plated bolts with an oxyacetylene torch. Based on the amount of cadmium oxide found in the welder's lung during a postmortem examination, the authors estimated that his exposure to cadmium oxide averaged 8.6 mg/m^3. Several other fatalities have resulted from pulmonary edema in welders exposed to nitrogen dioxide concentrations above 100 ppm [Maddock 1970].

b. Toxicological Evidence

Pathological lung changes observed in welders acutely exposed to welding fumes and gases have also been documented in exposed animals [Titus et al. 1935; Kawada and Iwano 1964; Hewitt and Hicks 1973].

Animals exposed to welding fumes and gases for short periods suffered severe lung damage (e.g., edema, hemorrhage, pneumonia, and atelectasis) and death. In one experimental study [Titus et al. 1935], cats and rabbits were exposed to iron oxide fumes for up to 8.5 hr at concentrations of 10 to 350 mg/m^3. All animals developed pulmonary edema. Their alveoli became dilated, their lungs hemorrhaged, and several died. Similar results were reported by Hewitt and Hicks [1973] in albino rats exposed to rutile welding fumes and gases at an average concentration of 1,500 mg/m^3. Rats exposed for either 30 min or 4 hr demonstrated a statistically significant ($p<0.05$) increase in uptake of chromium and antimony by the lungs, and of cobalt by the liver and blood. Microscopic examination of the lungs revealed peribronchial edema and large numbers of particulate-laden macrophages in the alveoli and alveolar ducts. Histopathological lung changes were reversed following 75 days with no exposure; only the particulate material remained within the macrophages.

Pulmonary deposition and clearance rates in animals exposed to fumes from welding nonstainless and stainless steels were investigated by McCord et al. [1941] and Byczkowski et al. [1970]. The rates of metal deposition in the lungs were proportional to the metal content of the emissions; these rates increased in animals that exercised during exposure.

2. Chronic Respiratory Diseases

a. Epidemiologic Studies

Pneumoconiosis, including siderosis, has been reported among welders exposed to iron oxide fumes from bare metal electrodes [Britton and Walsh 1940; Sander 1944; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950]. Although quantitative data on exposures are lacking for most of these studies, Dreesen et al. [1947] provide some data on the extent of exposures before 1950. Samples collected during arc welding of mild steel in a shipyard revealed iron oxide concentrations above 30 mg/m^3 and zinc oxide concentrations above 15 mg/m^3. The highest exposure concentrations were found in poorly ventilated work areas. Approximately 50% of the samples contained less than 5 ppm oxides of nitrogen, and 10% of the samples exceeded 25 ppm.

Other studies have described siderosis complicated by fibrosis [Marchand et al. 1964; Meyer et al. 1967; Stettler et al. 1977; Kleinfeld et al. 1969; Brun 1972; Levy and Margolis 1974; Attfield and Ross 1978]. These findings appear to be associated with the replacement of bare metal electrodes by covered electrodes. Clinical evaluations were made of workers who were exposed to iron oxides and silica and who welded both ferrous and nonferrous materials using covered electrodes. These evaluations revealed diffuse interstitial fibrosis [Meyer et al. 1967] and siderosilicosis [Levy and Margolis 1974]. Levy and Margolis [1974] reported peak airborne concentrations of 19.4 mg/m^3 for iron oxide and 6.82 mg/m^3 for respirable silica among steel foundry welders who had evidence of siderosilicosis.

Welders have also shown decrements in pulmonary function [Hunnicutt et al. 1964; Fogh et al. 1969; Keimig et al. 1983; Oleru and Ademiluyi 1987] and increases in the prevalence of chronic bronchitis [Kujawska 1968; Fogh et al. 1969; Barhad et al. 1975; Antti-Poika et al. 1977; Akbarkhanzadeh 1980; Sjogren and Ulfvarson 1985]. The only exposure data reported are those cited in the studies by Barhad et al. [1975], Sjogren and Ulfvarson [1985], and Keimig et al. [1983]. Barhad et al. [1975] reported that shipyard welders were exposed to total fume concentrations of 6 to 36 mg/m^3 in open work areas and 48 to 92 mg/m^3 in confined spaces during arc welding with covered electrodes. Oxides of nitrogen averaged concentrations of 1.7 mg/m^3 during shielded arc welding and 1.1 mg/m^3 during arc welding. Regardless of the welding process, carbon monoxide concentrations ranged from 6.3 to 17 mg/m^3. In the study by Sjogren and Ulfvarson [1985], exposures to ozone exceeded 0.1 ppm in 50% of the samples collected during gas metal arc welding of aluminum. During stainless steel welding with covered electrodes, 80% of the chromium(VI) concentrations exceeded 20 ug/m^3. Concentrations of nitrogen oxides were less than 5 ppm for all welding processes [Sjogren and Ulfvarson 1985]. Breathing zone air samples collected near welders at the time of the study reported by Keimig et al. [1983] indicated iron oxide concentrations of 1.3 to 8.5 mg/m^3, with no detectable amounts of chromium, copper, fluoride, or lead in any of the air samples.

The cross-sectional study reported by Keimig et al. [1983] found that welders and controls who smoked had higher frequencies of reported respiratory symptoms (e.g., bronchitis, pneumonia, and cough) than corresponding nonsmokers. Although welders who did not smoke reported higher frequencies of symptoms than nonsmoking controls, the differences were statistically significant ($p<0.05$) only for the symptoms of increased phlegm and episodes of cough and phlegm. The only statistically significant differences noted in pulmonary function tests were decreases in forced vital capacity (FVC) at the end of the work shift for nonsmoking welders, nonsmoking controls, and smoking controls.

Similar findings were reported by Oleru and Ademiluyi [1987] for a group of workers engaged in the welding of medium- and high-alloy steel. Although no evidence of obstructive lung disease was found, 7 of 67 persons tested had restrictive lung impairment. Welders given pulmonary function tests to assess the effects of exposure over a 40-hr work week demonstrated statistically significant ($p<0.05$) decrements in all parameters measured. Peak flow measurements made on this group after an 8-hr work shift showed acute changes in pulmonary function that were statistically significant ($p<0.05$). However, these changes were not statistically significant when the group was retested after 3 additional days of welding. In the studies by Hunnicutt et al. [1964], Fogh et al. [1969], and Akbarkhanzadeh [1980], the increased prevalence in decrements of pulmonary function or chronic bronchitis were observed only in welders who smoked.

b. Toxicological Evidence

Siderosis has been produced by exposing animals to mixed compositions of fumes [McCord et al. 1941; Garnuszewski and Dobrzynski 1966]. All rats and rabbits developed siderosis when they were exposed to shielded metal arc welding fumes for 6 hr/day, 5 days/week for 46 days followed by an additional 43 days without exposure [McCord et al. 1941]. Animals were exposed to average concentrations of 465 mg/m^3 (ferric oxide), 61 mg/m^3 (silicon dioxide), and 16 mg/m^3 (manganese). Similar results were produced by Garnuszewski and Dobrzynski [1966], who exposed groups of guinea pigs and rabbits to fumes that were either high in silicon oxide (25.5%) and low in ferric oxide (18%), or low in silicon oxide (7.8%) and high in ferric oxide (23%). Each experimental group of animals was subdivided into a high-exposure group (36 mg of total fumes/m^3 of air) or low-exposure group (18 mg of total fumes/m^3 of air). All animals were exposed 4 hr/day, 6 days/week for 110 days. All exposed guinea pigs developed a mixed type of pneumoconiosis (e.g., siderosis with silicosis manifested by pneumoconiotic nodules containing collagenous fibers and silica particles). No pneumoconiosis was observed in the exposed rabbits.

3. Other Adverse Health Effects

a. Auditory Impairment

Auditory impairment has been reported among welders as a result of traumatic injury [Frenkiel and Alberti 1977] or excessive sound pressure [Hickish and Challen 1963; Bell 1976]. Several cases of eardrum injury and permanent hearing loss were reported by Frenkiel and Alberti [1977] among welders who did not wear ear protection and were injured by sparks and molten metal that entered the ear while welding. Studies conducted by Hickish and Challen [1963] and Bell [1976] described the risk of noise-induced hearing loss in welders performing arc air gouging or plasma torch welding of metals. Mean temporary hearing losses of 19 dB at 4,000 Hz and up to 35 dB at 8,000 Hz were reported by Hickish and Challen [1963] among a group of welders who were performing plasma torch welding for 1 hr without wearing hearing protection.

b. Cardiovascular Disease

Studies that have assessed cardiovascular disease in welders have produced equivocal results. Two mortality studies indicate increased risks of death from cardiovascular disease among shipyard welders [Newhouse et al. 1985; Puntoni et al. 1979]. Newhouse et al. [1985] reported an increased SMR of 130 ($p=0.10$) for ischemic heart disease, and Puntoni et al. [1979] reported ORs greater than 1.00 for cardiovascular disease. Neither study adjusted for smoking habits, and no information was provided on other possible risk factors. Two other studies analyzed deaths from cardiovascular disease: An SMR reported by Polednak [1981] and a PMR by Milham [1983] were both less than 100. Although the association between welding and an increased risk of cardiovascular disease remains equivocal, the data do provide cause for concern.

c. Dermal Effects

Several types of dermal conditions observed in welders have been attributed to exposure to physical agents, including UV radiation [Grimm and Kusnetz 1962; Pattee et al. 1973; Balabanow et al. 1967; Roquet-Doffiny et al. 1977; Ross 1978], IR radiation [Lydahl and Philipson 1984; Moss et al. 1985], and metals to which workers can become sensitized [Kaplan and Zeligman 1963; Fregert and Ovrum 1963; Shelley 1964; Kalliomaki et al. 1977]. Chronic dermatitis and other skin diseases have been documented in several case reports [Shelley 1964; Balabanow et al. 1967; Roquet-Doffiny et al. 1977] that described welders whose skin came into contact with many types of metals (e.g., nickel, cadmium, and chromium) and fluxes. Welders exposed to welding fumes from stainless steel have experienced episodes of facial contact dermatitis [Fregert and Ovrum 1963]. In these cases, removal of the worker from exposure or the use of protective clothing eliminated or greatly minimized the severity of the disorder.

d. Eye Injuries

Welders or others working near welding processes risk eye injury from metal spatter, foreign bodies in the eyes, and exposure to nonionizing electromagnetic radiation [NIOSH 1972a; Marshall et al. 1977; Palmer 1983; BLS 1985]. Exposure to ultraviolet radiation (UV) from welding arcs has caused acute keratoconjunctivitis, also known as welder's flash or actinic ray photokeratitis [Minton 1949; Sykowski 1951]. Repeated episodes of welder's flash over a long period have caused cataracts [Golychev and Nikitina 1974]. Similarly, exposure to infrared radiation (IR) has caused thermal damage to the cornea and aqueous humor of the eye and has been associated with the formation of lenticular cataracts [Palmer 1983]. Such adverse ocular effects have been attributed to the improper use or absence of eye protection [Minton 1949; Sykowski 1951; Entwistle 1964; Karai et al. 1984].

According to Bureau of Labor Statistics (BLS) data for the period 1976-81, eye injury was the type of injury that welders reported most frequently. Such injuries were associated with exposure to radiation or foreign bodies in the eyes among welders and flame cutters [BLS 1985]. These recent data are consistent with earlier data [BLS 1983]. For the 1983 BLS report, data were collected over a 5-month period in 1978 from welders in 18 states (BLS 1983). Sixty-seven percent of the reported injuries were to the eyes. No information was given in either report as to whether eye protection was being worn at the time of the injury.

e. Gastrointestinal Disorders

Gastrointestinal disorders (e.g., nausea, vomiting, and gastrointestinal cramps) are often experienced by welders with metal fume fever, but they are reversible following treatment and removal of the worker from additional exposure [Rohrs 1957; Papp 1968]. Studies by Mignolet [1950], Stancari and Amorati [1963], and Rozera et al. [1966] reported digestive system disorders in welders that included gastritis, gastroduodenitis, and gastroduodenal ulcers. The authors attributed these conditions to long-term exposures to welding fumes and gases. Epidemiological studies of welders conducted by Puntoni et al. [1979], Polednak [1981], Milham [1983], and Becker et al. [1985] found no increases in mortality as a result of diseases of the digestive system.

f. Musculoskeletal Effects

Reports of musculoskeletal injuries involving the shoulders, back, and knees have been noted in several studies of welders [Herberts and Kadefors 1976; Kadefors et al. 1976; Nauwald 1980]. Complaints of shoulder pain and reduced muscle power, particularly of the supraspinatus muscle, have been frequently attributed to overhead welding performed by both inexperienced and experienced welders. Knee joint problems (including fluid sac diseases, arthritis, and proliferation of fatty tissue) have also been observed, primarily in welders with more than 6 years of experience.

g. Reproductive Effects

Studies conducted by Rachootin and Olsen [1983] and Lindbohm et al. [1984] suggest a possible association between adverse reproductive outcomes and the subject's status as a welder or as the wife of a metal plate worker. A statistically significant increase ($p<0.05$) in spontaneous abortions was observed for wives of metal plate workers [Lindbohm et al. 1984]. The authors suggested that this increase was caused by exposure to chromium or nickel. The case-control study by Rachootin and Olsen [1983] indicated a statistically significant increase ($p<0.05$) in delayed conception, with ORs of 1.4 for male welders and 2.4 for female welders. The risk remained statistically significant for women after adjustment for age, smoking habits, alcohol consumption, and past use of oral contraceptives. Men and women assigned to the subgroup "Welding of Stainless Steel" had no statistically significant increase in their risk of delayed conception. Although the studies suggest a reproductive risk, several methodologic problems exist, including the inability to accurately estimate possible exposures based on employment history [Lindbohm et al. 1984; Rachootin and Olsen 1983], the lack of information on smoking habits or alcohol consumption [Lindbohm et al. 1984], and possible data collection biases resulting from the use of self-administered questionnaires [Rachootin and Olsen 1983].

No experimental animal studies have been conducted to determine the effects of welding fumes and gases on the reproductive system.

E. Safety

Fires, explosions, and electric shocks are common welding hazards that have caused many disabling injuries and fatalities [BLS 1985]. Fires caused by the welding flame itself or by flying sparks have been responsible for many injuries and fatalities of welders [NFPA 1977; Buhrer and Brunschwiler 1978]. Injuries have also been reported as a result of accidental fires caused by welding in oxygen-enriched atmospheres in confined spaces or by oxygen leaks from welding tanks [Rames 1976]. Fires and explosions have also been caused by welding or cutting tanks and drums that have not been properly emptied and cleaned of flammable liquids [CDLSR 1975; NFPA 1977].

Electric shocks have occurred in welders using alternating or direct currents of 120 to 600 A at 30 to 60 volts. Even if the shock itself was harmless, resulting falls have caused serious injury or death [Britton and Walsh 1940]. Many of these incidents have occurred from improper grounding of the welding electrode or careless handling and changing of electrodes.

F. Conclusions

Epidemiologic studies and case reports of workers exposed to welding fumes and gases provide adequate evidence that these workers are at an increased risk of contracting acute respiratory diseases such as metal fume fever and pneumonitis [Drinker 1922; Drinker et al. 1927; Christensen and Olson 1957; Kleinfeld et al. 1957; Molos and Collins 1957; Rohrs 1957; Challen et al. 1958; Beton et al. 1966; Papp 1968; Townshend 1968; Blejer and Caplan 1969; Maddock 1970; Mangold and Beckett 1971; Ross 1974; Jindrichova 1976; Patwardhan and Finckh 1976; Herbert 1982; Johnson and Kilburn 1983]. Chronic respiratory diseases such as pneumoconiosis and bronchitis have also been documented in workers exposed to welding emissions [Britton and Walsh 1940; Sander 1944; Dreesen et al. 1947; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950; Hunnicutt et al. 1964; Marchand et al. 1964; Meyer et al. 1967; Kujawska 1968; Fogh et al. 1969; Kleinfeld et al. 1969; Brun et al. 1972; Levy and Margolis 1974; Barhad et al. 1975; Antti-Poika et al. 1977; Stettler et al. 1977; Attfield and Ross 1978; Akbarkhanzadeh 1980; Sjogren and Ulfvarson 1985; Keimig et al. 1986; Oleru and Ademiluyi 1987].

Some studies report that an increased risk of lung cancer is associated with welding on stainless steel [Sjogren 1980; Polednak 1981; Gerin et al. 1984; Sjogren et al. 1987], and the study reported by Polednak [1981] observed an increased risk in welders exposed to nickel oxides. Studies of welders exposed to fumes of mixed composition have also reported an increased risk of lung cancer [Beaumont and Weiss 1981; Breslow et al. 1954; HMSO 1978; Milham 1983; Puntoni et al. 1979; Becker et al. 1985; Newhouse et al. 1985; Steenland et al. 1986; Schoenberg et al. 1987].

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, including cancer. Thus even compliance with specific chemical or physical agent exposure limits may not ensure complete protection against an adverse health effect. Therefore, exposures to all chemical and physical agents associated with welding should be reduced to the lowest concentrations technically feasible using current state-of-the-art engineering controls and good work practices. Individual exposure limits for chemical or physical agents are to be considered upper boundaries of exposure.

Equivocal evidence exists to show the effects of welding emissions on (1) the increased risk of cancer at sites other than the lung [Olsen et al. 1984; Puntoni et al. 1979; Milham 1983; Becker et al. 1985; Roquet-Doffiny et al. 1977], (2) the cardiovascular system [Newhouse et al. 1985; Puntoni et al. 1979], and (3) the reproductive system [Rachootin and Olsen 1983; Lindbohm et al. 1984]. However, following the recommendations in this document should prevent or greatly reduce a welder's risk of developing these diseases. Following the recommendations should also reduce injuries and deaths resulting from unsafe work conditions.

VI. 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) 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 VI-1. Methods for monitoring physical agents are presented in Table VI-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 VI-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 VI-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. Appendix B lists 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 VI-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 VI-3.—Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Gases:			
Acetylene[c]	Anesthesia (at high concentration)	N/A	
Carbon monoxide	Headache, nausea, dizziness, collapse, death	Cardiovascular effects (cardio-myopathy, 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 VI-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 VI-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 VI-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]
Zinc	Metal fume fever[e], skin eruption (oxide pox)	Not known	
<u>Other minerals</u>:			
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	
<u>Physical agents</u>:			
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 VI-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	
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.

VII. 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 nanometers (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 thickness 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 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 booth 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

- 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.

VIII. RESEARCH NEEDS

Research is needed in several areas to evaluate the work-relatedness of disease symptoms in exposed workers who are associated with welding processes. The various chemical agents (fumes and gases) and physical agents generated during these processes need to be characterized, and their possible interactions need to be assessed. Long-term inhalation studies in animals, and morbidity and mortality studies of welders are needed to better define the relationship between exposure and respiratory disease, including lung cancer. Several studies have indicated that workers who smoke and weld have an increased incidence and severity of respiratory disease. This association should be clarified.

Several epidemiologic studies have shown statistically significant increases in the risk of lung cancer for workers who weld stainless steel. Thus the carcinogenic potential of stainless steel welding emissions needs to be better defined. Research is particularly needed to assess the carcinogenicity of chromium and nickel in the forms generated during this process. Comprehensive industrial hygiene evaluations are needed to quantitate exposure concentrations and ascertain past exposures. To make such evaluations, investigators must gather information on the types of welding performed, work practices and controls used, and composition of base metals, fluxes, and electrodes.

To simplify the task of repetitively characterizing work environments where welding processes are performed, researchers should pursue a means of indexing exposures by job type or process. Workplace exposures should be characterized by representative jobs and job sites with the use of personal and stationary samplers. The various components of the fumes and gases should be identified and quantified as a fraction of the total or respirable fumes. In addition, information should be gathered on the type of welding technology and welding consumables used. This information should take the form of a list of processes and their applications, the types of material they use, the nature of the workplace, and the type of job. Furthermore, the intensity of the work should be determined by estimates of arcing time per job shift, the number of electrodes consumed per unit of time, or the quantity of consumables purchased. Also, the use of any specific work practices or local exhaust ventilation should be recorded along with their effects on the extent and composition of the fume exposure.

Better control technology should be developed in the form of new welding processes and worker-protective measures to assure that the worker is protected to the greatest extent possible. The use of new metals, alloys, and complex composites of materials should be closely monitored and assessed for their potential to cause adverse health effects.

Recordkeeping and medical monitoring requirements proposed in this document need to be assessed for welders who change jobs frequently (e.g., welders in job shops or construction). Because of the short-term nature of these jobs, the recordkeeping and monitoring provisions of this document may not be readily implemented. Methods are also needed to prevent the replication of medical examination and monitoring records among various employers.

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APPENDIX A.—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

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See footnotes at end of table.

APPENDIX A (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

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See footnotes at end of table.

APPENDIX A (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 A (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 A (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 $\mu g/m^3$ TWA	Respirable dust for quartz and fused silica: 100 $\mu g/m^3$ Contained respirable quartz dust for tripoli: 100 $\mu g/m^3$ Respirable dust for cristobalite and tridymite: 50 $\mu g/m^3$
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 A (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 μg $nickel/m^3$, 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.

APPENDIX A (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.

APPENDIX B.--Published sources of NIOSH RELs for hazardous agents associated with welding processes

Hazardous agent	Publication
Acetylene	NIOSH (1976). Criteria for a recommended standard: occupational exposure to acetylene. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-195.
Arsenic, inorganic	NIOSH (1975). Criteria for a recommended standard: occupational exposure to inorganic arsenic. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 75-149.
Beryllium	Baier EJ (1976). Statement before the Department of Labor, Occupational Safety and Health Administration, Public Hearing on the Occupational Standard for Beryllium, Aug 19, 1977. Washington, DC: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health.
Cadmium	NIOSH (1984). Current intelligence bulletin no. 42--cadmium. U.S. Department of Health and Human Services, Centers for Disease Control, Public Health Service, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 84-116.

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APPENDIX B (Continued).--Published sources of NIOSH RELs for hazardous agents associated with welding processes

Hazardous agent	Publication
Carbon dioxide	NIOSH (1976). Criteria for a recommended standard: occupational exposure to carbon dioxide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-194.
Carbon monoxide	NIOSH (1973). Criteria for a recommended standard: occupational exposure to carbon monoxide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 73-11000.
Chromium(VI)	NIOSH (1975). Criteria for a recommended standard: occupational exposure to chromium(VI). Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-129.
Cobalt	NIOSH (1982). NIOSH occupational hazard assessment--criteria for controlling occupational exposure to cobalt. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 82-107.

(Continued)

APPENDIX B (Continued).--Published sources of NIOSH RELs for hazardous agents associated with welding processes

Hazardous agent	Publication
Fluorides, inorganic	NIOSH (1976). Criteria for a recommended standard: occupational exposure to inorganic fluorides. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-103.
Hot environments	NIOSH (1986). Criteria for a recommended standard: occupational exposure to hot environments--revised criteria 1986. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 86-113.
Lead, inorganic	NIOSH (1978). Criteria for a recommended standard: occupational exposure to inorganic lead. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 78-158.
Nickel, inorganic and compounds	NIOSH (1977). Criteria for a recommended standard: occupational exposure to inorganic nickel. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-164.

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APPENDIX B (Continued).--Published sources of NIOSH RELs for hazardous agents associated with welding processes

Hazardous agent	Publication
Noise	NIOSH (1972). Criteria for a recommended standard: occupational exposure to noise. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. HSM 73-11001.
Oxides of nitrogen	NIOSH (1976). Criteria for a recommended standard: occupational exposure to oxides of nitrogen. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-149.
Phosgene	NIOSH (1976). Criteria for a recommended standard: occupational exposure to phosgene. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-137.
Tungsten and cemented tungsten carbide	NIOSH (1977). Criteria for a recommended standard: occupational exposure to tungsten and cemented tungsten carbide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-227.

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APPENDIX B (Continued).--Published sources of NIOSH RELs for hazardous agents associated with welding processes

Hazardous agent	Publication
Ultraviolet radiation	NIOSH (1972). Criteria for a recommended standard: occupational exposure to ultraviolet radiation. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. HSM 73-11009.
Vibration	NIOSH (1983). Current intelligence bulletin no. 38--vibration syndrome. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 83-110.
Zinc oxide	NIOSH (1975). Criteria for a recommended standard: occupational exposure to zinc oxide. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-104.

APPENDIX C

American Thoracic Society

MEDICAL SECTION OF THE AMERICAN LUNG ASSOCIATION

STANDARDIZATION OF SPIROMETRY—1987 UPDATE

THIS OFFICIAL STATEMENT OF THE AMERICAN THORACIC SOCIETY WAS APPROVED BY THE ATS BOARD OF DIRECTORS, MARCH 1987.

Contents

I. INTRODUCTION

The American Thoracic Society (ATS) statement on the Standardization of Spirometry was published 8 years ago and was based on the Snowbird Workshop held in 1977 (1). Since that time, we have had years of practical experience with these recommendations, which have been widely endorsed (2-5). In addition, the "state of the art" of spirometry has advanced as a result of scientific studies that have provided additional data relating to performance of spirometry. Simultaneously, the use of computers for spirometry measurement has become commonplace. As a consequence, the American Thoracic Society's Board of Directors asked that the Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories review and update the initial statement.

The ATS statement on standardization of spirometry has had a far-reaching effect on manufacturers and users of spirometers. In some cases, manufacturers have used the document as a "minimum" performance requirements document. We are concerned with this approach and encourage manufacturers to continue to seek excellence in design so that the "state of the art" for spirometers will exceed the ATS recommendations. Some research protocols will necessitate even more stringent requirements than stated here.

We frequently hear the appeal that an inexpensive and, although not explicitly stated, "less accurate" spirometer is all that is needed in clinical practice. We feel this premise is flawed since treatment decisions need to be based on the best data available, whether data arises from a hospital-based diagnostic laboratory *or* a physician's office. During recent testing of commercially available spirometers, devices were found that had FVC errors as large as 1.5 L, a 25% error (6). If a bronchodilator treatment is made based on spirometric data, subsequent spirometric measurements are often made to determine if the treatment was effective. If an inaccurate spirometer is used, especially a spirometer with poor repeatability, the improvement or degradation measured may be entirely spirometer-related and have nothing to do with the subject's response to treatment.

Spirometry is used to affect decisions about individual patients such as: Does this subject have enough evidence of impaired lung function to preclude working at a specific job? Should steroid treatment be continued? Does this person qualify for full disability compensation on the basis of impaired lung function? Should the subject's insurance status be changed? Answers to each of these questions based on spirometric maneuvers can have a dramatic effect on a person's lifestyle, standard of living, and future treatment (5).

Similarly, accurate spirometers are required for epidemiologic studies. Rates of improvement or deterioration of pulmonary function measured in relation to environmental exposures and/or personal characteristics may be erroneous if inaccurate spirometers are used or less sensitive if imprecise spirometers are used (7).

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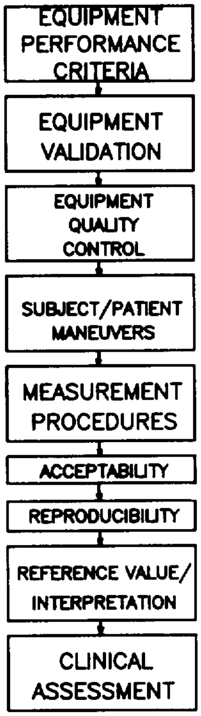

Fig. 1. Spirometry standardization steps.

Testing of commercially available spirometers, with a computer-driven mechanical syringe, has recently been completed. It was found that already 27 of 53 (51%) spirometers met the new and rigorous ATS recommendations outlined in this article. With the aid of microcomputers, several flowmeter type spirometers now meet the ATS requirements (6). Not surprisingly, computer software was one of the major reasons for device failure.

Maximizing the clinical usefulness of spirometry depends upon a number of factors, ranging from equipment selection to interpretation, and ultimately involves clinical assessment. Figure 1 is a flow diagram of these steps. The first step is choosing the equipment. The Snowbird Workshop (1) and now this update give recommendations for equipment used for spirometry. Spirometer users should carefully select equipment that meets the ATS recommendations to assure that spirometry testing can be done accurately. The second step in the process involves validating that the spirometer design and that a production device meet the recommendations. Detailed methods for performing the validation testing are outlined later in this article. Because almost no physicians and few clinical pulmonary function laboratories have the capability to exhaustively test and validate spirometers, an independent testing laboratory has been set up at LDS Hospital in Salt Lake City, Utah. Other independent laboratories are encouraged to enter the spirometer validation field.

The ATS promulgates standards but does not act as a certifying agency to verify compliance with these standards. Before a user purchases a spirometer, he or she would be wise to (*1*) ask the manufacturer to provide summary data that demonstrates that the device being considered meets the ATS recommendations, and (*2*) review results of spirometry testing from independent testing laboratories.

Even after the equipment has been found to meet ATS recommendations and has been validated, spirometers (like other pieces of mechanical, electrical, or computer equipment) must be routinely checked for performance quality. Recommendations for spirometer quality control have been developed by the ATS and are summarized in this article.

Spirometry is an effort-dependent maneuver that requires careful patient/subject instruction, understanding, coordination, and cooperation. Thus, performance recommendations are important components of testing. Part of the recommendation is to obtain a sufficient number of maneuvers that are of adequate quality and then determine if these acceptable maneuvers are reproducible. Once spirometry maneuvers have been performed, they need to be either measured by hand or by use of computer techniques. Measurement procedures are included in this article to help assure that uniform methods are used and that comparable results are obtained. These recommendations include considerations such as using "back extrapolation" for determining the "start of test" time zero point for determination of measures such as FEV_1.

Interaction between technician and patient or subject is crucial to performing adequate spirometry since it is such an effort-dependent maneuver. Technicians must be selected and trained and maintain a high level of proficiency to assure optimal results.

The effort-dependent spirogram must be carefully scrutinized for quality. Recommendations about quality, acceptability, and reproducibility of test result are presented. After adequate results are obtained, they are usually compared with reference values to make an assessment (interpretation) of the results. Future ATS efforts should be directed at investigating and providing guidelines for selecting reference values and interpretive methods. This article provides only background materials for these future developments.

Clinical assessment is a crucial part of the patient/subject-physician/investigator interaction and should be an integral part of the entire process. Results obtained from spirometry are only one part of the much more complex patient care relationship of research data analysis.

Definitions

Standard definitions are important to assure that everyone understands each test and its performance methodology. All terms and abbreviations used here are based on a report of the American College of Chest Physicians (ACCP)-ATS Joint Committee on Pulmonary Nomenclature (8).

II. EQUIPMENT RECOMMENDATIONS

Equipment selection is pivotal to acquiring accurate test results. Spirometer equipment recommendations apply to all diagnostic spirometers whether used for clinical, diagnostic, or epidemiologic purposes. Instrumentation recommendations should be followed to provide accurate spirometric data and information that is comparable from laboratory to laboratory and from one time period to another (1). The accuracy of a spirometer system depends on the resolution (i.e., the minimal detectable volume or flow) and linearity of the entire system – from volume or flow transducer to recorder, display, or processor. Errors at any step in the process affect the accuracy of the results obtained (see Appendix A). For example, if a sample point is not available at exactly 1.0 s after the back extrapolated "time zero," then linear interpolation of the volume curve should be used to find FEV_1.

The equipment recommendations for spirometry are summarized in table 1.

Recommendation – Vital Capacity (VC)

VC = The maximal volume of air exhaled from the point of maximal inhalation. This is also considered the "slow" vital capacity. Expressed in liters (BTPS). BTPS = Body conditions: normal body temperature (37° C), ambient pressure, saturated with water vapor.

Recommendation – VC Equipment

If a spirometer purports to measure VC, it should continue to accumulate volume for *AT LEAST* 30 s. Spirometers should be capable of measuring volumes of *AT LEAST* 7 L (BTPS) with flows between zero and 12 L/s. Accuracy required is *AT LEAST* ± 3% of reading or ± 0.050 L, whichever is greater.

Rationale. Based on Hankinson and Petersen's data on 9,347 working coal miners, the range for volume and flow were established (1, 9). Of these miners, 99.25% had a forced vital capacity of less than 7.25 L (1). If the spirometer is used for both inspiration and expiration, a volume capacity of greater than 7 L may be necessary. The volume requirement of 7 L also applies to children (1, 3, 10, 11). Older men and women have volumes similar to those of adolescents (10–12). A 7-L spirometer will not measure the person with "super" lungs, but it will cover the majority of the population. Accuracy of ± 3% of reading or ± 0.050 L, whichever is greater, is based on the data of Hankinson and Petersen (1, 9). Their data showed coefficient of variation on the same subject on different days of 3% or less (1). These data have been substantiated (13–15). A spirometer must be capable of measuring flows in the range of zero to 12 L/s. The 12 L/s maximal flow rate selection was determined from Hankinson and Petersen's data (1, 9) that showed that less than

TABLE 1

MINIMAL RECOMMENDATIONS FOR SPIROMETRY SYSTEMS

Test	Range/Accuracy BTPS (L)	Flow Range (L/s)	Time (s)	Resistance and Back Pressure	Test Signal
VC	7 L ± 3% of reading or ± 0.050 L, whichever is greater	zero to 12	30		3-L Cal Syringe
FVC	7 L ± 3% of reading or ± 0.050 L, whichever is greater	zero to 12	15		24 standard waveforms
FEV_t	7 L ± 3% of reading or ± 0.050 L, whichever is greater	zero to 12	t	Less than 1.5 cm H_2O/L/s, from zero to 12 L/s	24 standard waveforms
Time Zero	The time point from which all FEV_t measurements are taken.			Determined by back extrapolation.	
$FEF_{25-75\%}$	7.0 L ± 5% of reading or ± 0.200 L/s, whichever is greater	zero to 12	15	Same as FEV_t	24 standard waveforms
$\dot{V}$	± 12 L/s ± 5% of reading or ± 0.200 L/s, whichever is greater	zero to 12	15	Same as FEV_t	Manufacturer proof
MVV	Sine wave 250 L/min at TV of 2 L within ± 5% of reading	zero to 12 ± 5%	12 to 15 ± 3%	Pressure less than ± 10 cm H_2O at 2-L TV at 2.0 Hz	Sine wave pump zero to 4 Hz ± 10% at ± 12 L/s

about 7% of the miners had flow rates greater than 12 L/s.

Recommendation—Forced Vital Capacity (FVC)

FVC = Maximal volume of air exhaled with maximally forced effort from a position of maximal inspiration. Vital capacity performed with a maximally forced expiratory effort. Expressed in liters (BTPS).

Recommendation—FVC Equipment

The spirometer should be capable of measuring volumes up to *AT LEAST* 7 L (BTPS) with an accuracy of *AT LEAST* ± 3% of reading or ± 0.050 L, whichever is greater, with flows between zero and 12 L/s. The spirometer should be capable of accumulating volume for *AT LEAST* 15 s, although longer times are recommended.

Rationale. Subjects and patients can exhale for longer than 15 s, so instruments should be capable of measuring their true FVC. For the FVC maneuver, the volume requirements are the same as for the VC (1, 9-13). The spirometer must be capable of measuring flows in the range of zero to 12 L/s. The 12 L/s maximal flow rate selection was based on the Hankinson and Petersen data that showed that fewer than 7% of their coal miners had peak flows greater than 12 L/s (1, 9).

Recommendation—Timed Forced Expiratory Volume (FEV_t)

FEV_t = The volume of air exhaled in the specified time during the performance of the FVC, e.g., FEV_1 for the volume of air exhaled during the first seconds of FVC. Expressed in liters (BTPS).

Recommendation—FEV_t Equipment

Measuring the FEV_t requires a spirometer having a volume of *AT LEAST* 7 L. The spirometer should measure the FEV_1 within an accuracy of *AT LEAST* ± 3% of reading or ± 0.050 L, whichever is greater with flows between zero and 12 L/s. The "start of test" for purposes of timing WILL BE determined by the back extrapolation method (1, 16, 17) or a method shown to be equivalent (see figure 2). For hand measurements, the back extrapolation method traces back from the steepest slope on the volume-time curve (see figure 2) (17, 18). For purposes of computer methods of back extrapolation, we recommend using the largest average slope over a 70-ms period (19) (see Appendix A). The resistance to airflow from zero to 12.0 L/s should be less than 1.5 cm H_2O per L/s.

Rationale. FEV_t measurement is influenced by the point selected as the start of the maneuver. A uniform method of selecting the point is required to maintain consistency. The back extrapolation (1, 16, 17) method is the most consistent and accepted method (see Section VI for measurement procedures) and should be used until other methods are demonstrated to give equivalent results. One attempt to demonstrate equivalency of volume or flow threshold methods for detection of start of test by back extrapolation was unsuccessful (20). Resistance to flow affects the FEV_1 and other timed expirations (21-26).

Recommendation—$FEF_{25-75\%}$

$FEF_{25-75\%}$ = Mean forced expiratory flow during the middle half of the FVC. Formerly called the maximal midexpiratory flow rate (MMEF). Expressed in liters/sec (BTPS).

Recommendation—$FEF_{25-75\%}$ Equipment

The $FEF_{25-75\%}$ should be measured with an accuracy of *AT LEAST* ± 5% of reading or ± 0.200 L/s, whichever is greater. The $FEF_{25-75\%}$ should be measured on a system that meets the FVC recommendations.

Rationale. The $FEF_{25-75\%}$ maneuver has a much larger intrasubject variability than FVC or FEV_1 (27). Additionally, 2 measurements of both volume and time are required; therefore, the relaxed accuracy requirement is justified. Manufacturers and software developers should be aware that a major error in $FEF_{25-75\%}$ can occur when slow sampling rate analog to digital converters are used. With these systems, it may be necessary to "interpolate" between sample points to get the exact 25% and 75% of FVC points.

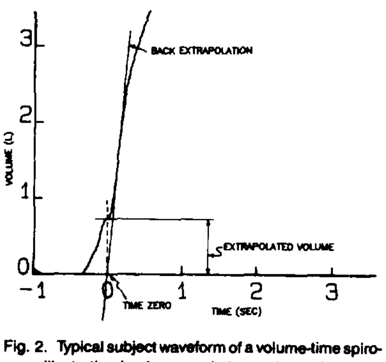

Fig. 2. Typical subject waveform of a volume-time spirogram illustrating back extrapolation to determine "time zero." Extrapolated volume = V_{ext}.

Recommendation—Flow ($\dot{V}$)

$\dot{V}$ = Instantaneous forced expiratory flow. Expressed in liters/sec (BTPS).

Recommendation—Flow Measurement

Flow may be measured electronically or manually. Where flow-volume loops or other uses of flow are made, with flow in the range of −12 to 12 L/s, the flow should be within ± 5% of reading or ± 0.200 L/s, whichever is greater.

Rationale. Flow-measuring devices such as pneumotachometers are increasingly being used to measure spirometric parameters (6). With flow devices, volume is determined by integration of flow. Flow calibration methods with sufficient accuracy have not yet been developed. Volume spirometers differentiate volume signals to determine flow. With the "noise," phase shift, and associated problems, flows accurate to within ± 5% are thought to be adequate. Whenever a flow signal is integrated to measure volume, the volume accuracy requirements are ± 3% of reading or ± 0.050 L, whichever is greater (1). Instantaneous flow parameters such as $FEF_{75\%}$, FEF_{max}, and Peak Expiratory Flow Rate (PEFR) are very device-dependent, and as a consequence their measurements are quite variable (6).

Recommendation — Forced Expiratory Time (FET)

FET = Time from the back extrapolated "time zero" until the first *in*spiratory effort following FVC, or the end of expiratory effort.

Rationale. The FET helps show that the duration of FVC effort was acceptable, an especially useful measure when using flow/volume loops.

Recommendation — Maximal Voluntary Ventilation (MVV)

MVV = The volume of air exhaled in a specified period during repetitive maximal respiratory effort. Expressed in liters/min (BTPS).

Recommendation — MVV Equipment

When a spirometer is used for measuring MVV, it should have an amplitude-frequency response that is flat within ± 10% from zero (DC) to 4 Hz at flow rates of up to 12 L/s over the volume range. The time for exhaled volume integration or recording should be no less than 12 or more than 15 s (21). The indicated time should be accurate to within ± 3%.

Rationale. For the MVV maneuver, the frequency content of the volume-time signal is high (28, 29). Results are dependent on the patient effort as well as the frequency response characteristics of the spirometer (21, 30–32).

General Background — Spirometry Recorders/Displays

Paper records or graphic displays of spirometry signals are **REQUIRED** and are used for 3 primary purposes:

(*1*) *DIAGNOSTIC* function — when waveforms are to be used for quality control or review of the forced expiratory maneuver to determine if the maneuver was performed properly, so that unacceptable maneuvers can be eliminated.

(*2*) *VALIDATION* function — when waveforms are to be used to validate the spirometer system hardware and software for accuracy and reliability through the use of hand measurements (for example, measurement of FEV_1 using back extrapolation by comparing computer- and hand-determined FEV_1).

(*3*) *HAND MEASUREMENT* function — when waveforms are to be hand measured for spirometric parameters (FVC, FEV_1, etc.) in the absence or failure of a computer.

With recent advances in computer technology, there are many different ways to display and record spirometric waveforms. The Committee has chosen to broaden the initial scope of the spirometry standardization article to further encourage use of computer technology.

A less stringent paper recorder requirement will suffice for *DIAGNOSTIC* purposes compared to *VALIDATION* and *HAND MEASUREMENT* needs. If no paper recorder or printer is available or if the paper recorder does not meet the requirements for *VALIDATION* and *HAND MEASUREMENT* applications, then proof of validation of the accuracy and stability of the spirometer by an independent laboratory *MUST* be provided by the manufacturer. For these computer methods, any new software releases *MUST* also be validated. *Users and manufacturers* should realize that for certain applications (for example, for disability determination and legal cases), diagnostic size displays are NOT adequate (21). For example, with the Cotton Dust standard ". . . tracings must be stored and available for recall and must be of sufficient size that hand measurements may be made. . ." (33). Also users will customarily not be able to verify accuracy and stability of spirometers by themselves in the absence of an adequate paper recording.

TABLE 2

MINIMUM REQUIRED SCALE FACTORS FOR TIME, VOLUME, AND FLOW GRAPHICS

	Diagnostic		Validation and Measurement	
	Resolution Required	Scale Factor	Resolution Required	Scale Factor
Volume (L)	0.050		0.025	
(mm/L)		5		10
Flow (L/s)	0.20		0.10	
(mm/L/s)		2.5		5
Time (msec)	20		20	
(cm/s)		1		2

Recommendation — FVC Volume-Time Curves

When a volume-time curve is plotted or displayed, the volume scale for each of the following conditions should be *AT LEAST*:

(*1*) *DIAGNOSTIC* function: 5 mm/L (BTPS) for volume so the graphs will be large enough to allow recognition of unacceptable maneuvers and disease patterns.

(*2*) *VALIDATION* and *HAND MEASUREMENT* functions: 10 mm/L (BTPS) for volume for validation and measurement functions. See section below for time scale of volume-time plots.

Recommendation — FVC Maneuver Time Scale

(*1*) *DIAGNOSTIC* function: time scale, *AT LEAST* 1 cm/s.

(*2*) *VALIDATION* and *HAND MEASUREMENT* functions: time scale, *AT LEAST* 2 cm/s; larger time scales are preferred (at least 3 cm/s) when hand measurements are made, but are not required (1, 34, 35).

Rationale. A recent study (35) evaluating the effects of time scale (paper speed) on spirometry accuracy has recommended a time scale of at least 3 cm/s if spirograms are to be accurately measured by hand. The adoption of this more stringent criterion was considered, but not adopted as a minimum recommendation. The new study further supports the current 2 cm/s requirement as a minimum recommendation (35). Because so many spirometers now make use of computers, time resolution and sampling rate become important design issues. The tutorial in Appendix A and table 2 give further specification details.

Recommendation — Flow-Volume Curves

When a flow-volume curve is plotted or displayed, exhaled flow should be plotted upwards, and exhaled volume towards the right. A 2:1 ratio should be maintained between the flow and volume scales, e.g., 2 L/s of flow and 1 L of exhaled volume should be the same distance on their respective axes. The minimum flow and volume scales should be *AT LEAST* as shown in table 2.

Rationale. Currently, flow-volume curves are displayed with a variety of orientations and aspect ratios, hindering the usefulness of visual pattern recognition. Also, some current digitally generated curves do not have sufficient flow or volume resolution. Manufacturers and users should be aware of these limitations.

III. EQUIPMENT VALIDATION

Recommendation — FVC Validation of Test Equipment

The diversity of FVC maneuvers encountered in clinical practice are currently best simulated by the use of the 24 standard waveforms developed by Hankinson and Gardner (19, 36). These waveforms can be used to drive a computer-controlled mechanical syringe for testing actual hardware and software, (6, 37) or they can be put into a system in digital form to evaluate ONLY the software. Appendix C shows a volume-time and a flow-volume plot of each of the 24 standard waveforms and includes table 4, which gives the measured values. The American Thoracic Society also provides these waveforms on floppy disks for an IBM PC. Appropriate corrections for using gas at ambient temperature, ambient humidity instead of BTPS may need to be made for some mechanical syringe-spirometer combinations.

The validation limits for volume are: Volume (FVC, FEV_1) ± 3.5% of reading or ± 0.070 L, whichever is greater; and Flow ($FEF_{25-75\%}$) ± 5.5% of reading or ± 0.250 L/s, whichever is greater. The error range was expanded from the ATS spirometry recommendation stated earlier to allow for errors associated with mechanical syringes (6). Mechanical syringes used for validation must be accurate within ± 0.025 L for FVC and FEV_1 and ± 0.100 L/s for $FEF_{25-75\%}$.

Rationale. Since the publication of the ATS spirometry statement, additional efforts by the Association for the Advancement of Medical Instrumentation (AAMI) (36) have resulted in the development of 24 standard waveforms for spirometer evaluation (19). Because these waveforms were obtained from recordings of actual subject waveforms and have been accepted by AAMI, and because better standard signals are not available, the ATS recommends their use as a test signal for FVC for evaluation of software or entire spirometry systems. When evaluating spirometers in which the 24 standard waveform sets are injected from a computer-controlled mechanical syringe (6, 37), the spirometer will qualify as meeting ATS requirements if fewer than 1 in every 20 measured values is outside the limits, provided the failure does not represent an inherent design defect.

Flows cannot be easily generated without noise; therefore, the frequency of the noise should be stated. In addition, a step function signal should be generated with the mechanical syringe, and the resulting signal should be sampled at a frequency of at least 1,000 Hz to determine the dynamic characteristics of the driving syringe. Typically, these systems have second-order oscillatory characteristics. By using the step function signal, the natural frequency and damping coefficients can be determined. Some spirometer manufacturers have appropriately purchased a computer-based syringe system for dynamic testing of each of their own spirometers (MH Custom Design and Manufacturing, 70 Fern Drive, Midvale, UT 84047); however, spirometry system designs and a production model must be validated by an independent testing laboratory.

Recommendation – MVV Validation Equipment

When tested with a pump producing a sinusoidal waveform, the indicated response of the spirometer in incrementally increased flows up to 250 L/min signal, produced with stroke volumes up to 2 L, should be accurate within ± 5% of reading. During the testing, the pressure at the mouthpiece should not exceed ± 10 cm H_2O. For volume spirometers, these requirements apply throughout their volume range.

IV. EQUIPMENT QUALITY CONTROL

Routine equipment preventive maintenance, cleaning, calibration checks, verification, and quality control are important to assure accurate spirometry results (38). A spirometry procedure manual is an important base for a quality assurance program. The manual should contain a quality control plan, guidelines for ordering spirometry, guidelines for performing spirometry, and guidelines for reporting spirometry results. See the document "ATS Quality Assurance for Pulmonary Laboratories" for more details (38).

The role of spirometric equipment in the transmission of infections has not been established (39). However, general suggestions based on a reasonable theoretical rationale or data from other sources are appropriate. A recent publication by the Centers for Disease Control outlines 9 recommendations: (*1*) handwashing indications, (*2*) handwashing technique, (*3*) handwashing products, (*4*) handwashing facilities, (*5*) fluids and medications, (*6*) handling blood specimens, (*7*) maintenance of equipment, (*8*) protection of patients from other infected/colonized patients or staff, and (*9*) microbiologic monitoring (39).

Recommendation – Equipment Quality Control

The spirometer's ability to accurately measure volume should be checked *AT LEAST* daily with a calibrated syringe with a volume of at least 3 L. During industrial surveys or other field studies in which a large number of subject maneuvers are done, the equipment should be calibrated prior to testing daily if in regular use and then every 4 h during use (38). Although there is minimal day-to-day variation in volume calibration, daily calibration checking is highly recommended so that the onset of a problem can be determined within 1 day, eliminating needless reporting of false values for several weeks or months and also to help define day-to-day laboratory variability. For survey testing in which a large number of maneuvers are done, the 4-h period of calibration checking is recommended to prevent invalidation of data from a large number of maneuvers. Spirometer systems should be evaluated for leaks on a daily basis (17, 40). The Intermountain Thoracic Society Manual suggests that leaks can be detected by applying a constant positive pressure of 3 cm H_2O or more with the volume spirometer outlet occluded. Any observed volume change after 1 min is indicative of a leak (17). *AT LEAST* quarterly, volume spirometers should have their calibration checked over their entire volume range (in 1-L increments) using a calibrated 3-L syringe (6). Two emptying times for the 3-L syringe are indicated: 0.5 to 1 s (flow in the range of 3 to 6 L/s) and at least 6 s (flows less than 0.5 L/s). Assessing the recorder time scale accuracy with a stopwatch should be performed *AT LEAST* quarterly. An accuracy of within 1% should be achieved. If equipment is changed or relocated (e.g., industrial surveys), calibration checking and quality control procedures should be repeated prior to initiating further testing.

V. MANEUVER PERFORMANCE RECOMMENDATIONS

Personnel Qualifications

The ATS has made recommendations for laboratory personnel performing a variety of pulmonary function testing tasks (41). In addition to recommending at least a high school training background, strong mathematics training was encouraged. Also 1 or more years of college or equivalent training are preferred for technicians performing spirometry. For pulmonary function laboratories, 6 months of supervised training time is recommended for performing spirometry. If troubleshooting is to be a part of the laboratory technician's responsibility, a training period of 1 year is recommended. The ATS has taken a strong position that the Medical Directors must have appropriate training and be responsible for all pulmonary function testing (42). Training for doing epidemiologic spirometric testing may be more intensive than that of a technician for a general pulmonary laboratory testing and may thus be accomplished more quickly. For industrial/occupational testing, there are training requirements mandated by the National Institute for Occupational Safety and Health (NIOSH) and industry and the ACCP (18, 33, 43).

Several excellent training manuals have been prepared for performance of spirometry (17, 18, 33, 44), and NIOSH approves training courses (18).

Rationale. The testing of equipment and wide-scale proficiency testing of pulmonary function equipment is not currently feasible. However, using laboratory personnel as "known subjects" and performing intralaboratory and inter-laboratory testing can be helpful (38). In addition, the ATS has recently published guidelines for "Quality Assurance in Pulmonary Function Laboratories," (38) which are recommended.

With the decrease in size and cost of microprocessors and the increase in their speed and reliability, most spirometer systems will contain some type of digital computer. Indeed, in a recent test of 53 commercially available spirometers, only 3 did not contain a computer (6). New quality assurance problems will occur as pulmonary function laboratories become more reliant on digital computers and associated automation (45, 46).

The use of computers to perform spirometry has accelerated in the past 5 years and this trend may be advantageous to obtain accurate spirometry (5, 35). The recent testing of commercially available spirometers showed that a major source of errors was in computer software (6). Because of the increased use of computers in pulmonary laboratories and the problems associated with them (6, 45), the ATS has published "Computer Guidelines for Pulmonary Laboratories" (46), which should be followed.

Recommendation – FVC Subject Instruction and Maneuver

Subjects will be instructed in the FVC maneuver, and the appropriate technique will be *demonstrated*. A *MINIMUM* of 3 acceptable FVC maneuvers will be performed. If a subject has large variability between expiratory maneuvers, reproducibility criteria may require that up to 8 acceptable maneuvers be

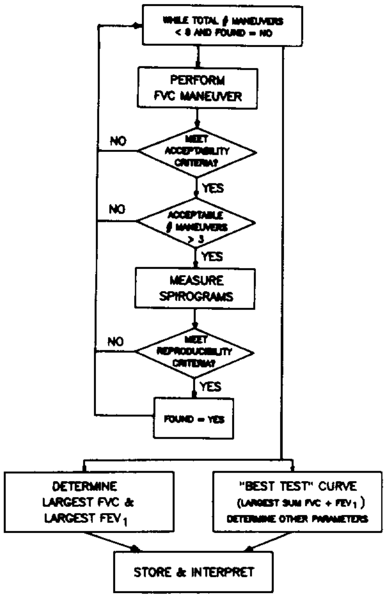

Fig. 3. Flow-chart diagram of FVC spirometry testing.

performed. See figure 3 and Section VII for further clarification.

Recommendation—FVC End of Test Criteria

Subjects should be verbally exhorted to continue to squeeze out the air at the end of the maneuver. "End of Test" will occur when there is:

(*1*) an obvious plateau in the volume-time curve resulting in no change in volume for *AT LEAST* 2 s (a volume decrease is, for the purposes of end of test selection, equivalent to no change in volume) with an exhalation time of *AT LEAST* 6 s (longer times are frequently needed for subjects with airway obstruction). For the purposes of this criterion, no change in volume is the minimal detectable volume of the spirometer. Minimum detectable volume MUST BE AT LEAST 0.040 L; OR

(*2*) a forced exhalation of reasonable duration. (For example, exhalation times of greater than 15 s in subjects with severe airway obstruction will rarely change clinical decisions and longer exhalations are seldom justified; manufacturers should note, however, that several of the 24 test waveforms have durations longer than 20 s); OR

(*3*) when, for legitimate clinical reasons, the subject cannot or should not continue further exhalation.

Although the end of test criteria defined above are reasonable and will perform adequately in most situations, spirometers should not prevent the continued accumulation of volume after the end of test criteria are met. We encourage spirometer designs that allow technicians to encourage subjects to breathe out for as long as they can or until there is an inspiration.

Rationale. A recent study (19) using standard waveforms has shown that application of the earlier ATS-recommended "end of test" criteria (1) prematurely terminates the FVC maneuver, resulting in as much as a 9% reduction in the measured FVC. Because the original recommendation was not based on data from subjects that covered the full spectrum of the population, the "end of test" criteria are now being updated.

Requiring that there be no change in volume for at least 2 s is probably similar to longstanding manual methods. We were reluctant to use the minimum volume accuracy of 0.050 L for the minimum detectable volume because most spirometers can resolve volume less than 0.050 L. Manual spirometers with a strip chart recorder can typically resolve 0.025 L, and a spirometer with a digital shaft encoder can typically resolve a 0.010-L volume (47). The second "end of test" criterion (*reasonable duration of 15 s*) is necessary to avoid prolonged expirations in subjects with severe airway obstruction in which more prolonged expiratory efforts will not change the clinical decision.

Recommendation—Minimum FVC Exhalation Time

A minimum exhalation time of 6 s, unless there is an obvious plateau, is required to obtain maximal FVC results. Longer times are often required to achieve "end of test," particularly in obstructed individuals.

Recommendation—FVC Satisfactory Start of Test Criteria

To achieve accurate "time zero" and ensure that the FEV_1 comes from a maximal effort curve, the extrapolated volume should be less than 5% of the FVC or 0.100 L, whichever is greater. See figure 2 for example of back extrapolation.

Rationale. The allowable extrapolated volume of the current ATS recommendations was 10% of the FVC or 0.100 L, whichever was greater, which can result in very slow starts with low peak flows being acceptable (1, 48–50). In addition, FEV_1 from submaximal efforts can be larger than those obtained when a maximal effort is performed, both due to a volume of air being exhaled without being timed (the extrapolated volume) and to less dynamic compression of airways in some subjects with submaximal efforts. Because the largest FEV_1 is reported, a falsely elevated FEV_1 may be used in the final report. The lower allowable extrapolated volume should reduce the effect of submaximal effect on the reported FEV_1.

Recommendation—FVC: Maximum Number of Maneuvers

Although there may be some circumstances in which more than 8 consecutive FVC maneuvers are needed, 8 maneuvers is considered a practical upper limit for most subjects.

Rationale. After several forced expiratory maneuvers, fatigue begins to take its toll on subjects and, thus, on their spirometric parameters. In addition, some subjects may exhibit spirometry-induced bronchospasm, and additional maneuvers would be of little added value. Therefore, an upper limit of the number of maneuvers is warranted. Ferris and associates (51) and Kanner and colleagues (15) have reported that for adults and children, 8 maneuvers is a practical upper limit.

Recommendation—FVC Environmental Conditions

Spirometric testing with ambient temperatures less than 17° C or more than 40° C is not recommended. Ambient temperature should ALWAYS be recorded and reported to an accuracy of ± 1° C. Spirometer users should be aware of the problems with testing done at lower temperatures. Ranges of barometric pressures that are acceptable for the spirometer should be published by the manufacturer.

Rationale. There is evidence that some subjects may develop airflow limitation with the inhalation of very cold air. Therefore, spirometry should not be conducted when the ambient temperature is cold enough to induce airflow limitation.

Recent studies also point out the problem of finite cooling times of gases in volume type spirometers and their associated tubing (52–54). In one of these studies, it was found that a + 7.7 to 14% error of FEV_1 results if the volume type spirometer is at an ambient temperature of 3° C, even with the BTPS correction. This error is less if the spirometer is warmer (nearer body temperature) (52). As a result, 17° C was judged to be an acceptable and reasonable lower limit.

Complexities related to temperature are also encountered with flow-measuring devices (54–57). Air exhaled from the mouth is estimated to be at 33° C (55, 56). If any connecting tubing is used between the mouthpiece and the flow sensor, the exhaled gas will experience a variable amount of cooling if the room temperature is not at 33° C. Details of the cooling pattern for flow spirometers have not been studied, but they may result in errors similar to those for volume devices (54–58).

Because not all spirometers are used at sea level (BP = 760 mm Hg), the range of barometric pressures allowed by the spirometer and its associated computational equipment should be specified.

Recommendation—FVC Use of Nose Clips

Use of nose clips is encouraged.

Rationale. Although the use of nose clips does not appreciably influence the FVC performed using the open circuit technique, some subjects breathe through the nose during the maneuver when a closed circuit technique is used.

Recommendation—FVC Sitting Versus Standing

Subjects may be studied in the sitting or standing position. Indication of position is necessary.

Rationale. Recent studies by Townsend show that for adults there are significantly larger forced expiratory volumes in the standing position than in the sitting position (59). The earlier ATS recommendation indicates that in children, VC is greater in the standing than in the sitting position (1).

VI. MEASUREMENT PROCEDURES

Measurement

Spirometric variables should be measured from a series of *AT LEAST* 3 acceptable forced expiratory curves.

Rationale. Best efforts cannot always be determined by simple inspection of a spirogram. Measurements and calculation are required to determine the largest values.

Recommendation—Test Result Selection/Reporting of Results

The largest FVC and the largest FEV_1 (BTPS) should be recorded, after examining the data from all of the acceptable curves, *even if the 2 values do not come from the same curve.* Other measures such as the $FEF_{25-75\%}$ and/or the instantaneous expiratory flows ($\dot{V}$) should be obtained from the single "best test" curve (1, 17). The "best test" curve is defined as the test that meets the acceptability criteria and gives the largest sum of FVC plus FEV_1.

Rationale. Two competing methods for selection of FVC and FEV_1 values have been used: (*1*) using the largest FVC and the largest FEV_1 independent of which acceptable curve they came from, or (*2*) using the FVC and FEV_1 from the single "best test" curve with the largest sum of FVC plus FEV_1.

As a result of the original recommendations made by the ATS Snowbird Workshop, several investigators have evaluated the use of the "best test" method (60–62). The University of Arizona group used the single "best test" to reevaluate their data and found that construction of "composite" maximal expiratory flow-volume (MEFV) curves gave results that were systematically higher than taking data from a "best test" waveform (60, 61). Sorensen and associates demonstrated that differences between maximal and "best test" FVC and FEV_1 were small. The mean difference between the 2-test result selection methods was only 5.8 ml for FVC and 8.4 ml for FEV_1. In 98.4% of the FVC comparisons and 95.7% of the FEV_1 comparisons, the differences were within the minimal spirometer accuracy recommendations (± 0.050 L or ± 3% of reading) (62).

The Committee decided to continue with the original Snowbird recommendation of taking the largest FVC and the largest FEV_1 independent of which curve they came from for the following reasons: (*1*) A large base of data, especially from epidemiologic studies, has been collected with the current recommended methods, and because the differences between "largest" and "best test" were small, no change in the recommendation was justified. (*2*) The FVC and FEV_1 are independent and therefore may be selected from different curves. (*3*) The largest values represent a subject's highest potential values and therefore should be used for legal/regulatory purposes. In fact, these regulations are already in place and will not likely change.

Because the average differences between the 2 methods are so small (< 10 ml), any reference value studies (63) or epidemiologic studies previously done with the "best test" method are still valid.

VII. ACCEPTABILITY AND REPRODUCIBILITY

Recommendation—FVC Maneuver Acceptability

Acceptability will be determined by ascertaining that the recommendations outlined above in the section on performing the FVC test are met. In review, these are: (*1*) end of test criteria, (*2*) minimum FVC exhalation time of 6 seconds, and (*3*) satisfactory start of test. In addition, the technician should observe that the subject understood the instructions and performed the maneuver with a maximum inspiration, with a good start, with a smooth continuous exhalation, with maximal effort, and without:

(*1*) An unsatisfactory start of expiration, characterized by excessive hesitation or false start or extrapolated volume of greater than 5% of FVC or 0.100 L, whichever is greater.

(*2*) Coughing during the first second of the maneuver, thereby affecting the measured FEV_1 value, or any other cough that, in the technician's judgment, interferes with measurement of accurate results.

(*3*) Valsalva maneuver (glottis closure).

(*4*) Early termination of expiration. (In a NORMAL subject this would be before completion of the breath—*USUALLY less than a 6-s maneuver.* In an obstructed subject, a longer time is required ([64, 65]).

(*5*) A leak.

(*6*) An obstructed mouthpiece, e.g., obstruction due to the tongue being placed in front of the mouthpiece, false teeth falling in front of the mouthpiece, etc.

Figure 3 is a flow chart outlining how acceptability and reproducibility criteria are to be applied.

Rationale. Many patients cough and sputter toward the end of their FVC maneuver, but this does not affect the important initial spirometry parameters. To eliminate these FVC maneuvers from clinical evaluation would be a waste of useful information. *AT LEAST* 3 acceptable maneuvers are required to ensure that maximal effort and cooperation are obtained and that the resulting data provide an accurate reflection of the subject's pulmonary function (1). This conclusion was achieved after reviewing the data of Knudson and associates (66) and others (17, 67).

Recent studies (48–50) have shown that the elimination of subjects for failure to meet the ATS reproducibility criteria may result in elimination of data from subjects who have abnormal lung function, resulting in a population bias. Pennock and colleagues (68) have reported that subjects with obstruction have greater coefficients of variation than do normal subjects. Therefore, these subjects are more likely to be unable to meet the ATS minimum reproducibility criteria. The reproducibility criteria have been clarified to eliminate confusion. If acceptability criteria are not applied before the reproducibility criteria, then a passive exhalation maneuver will often be labeled as the "best" maneuver because it may give the largest sum of FVC plus FEV_1.

Recommendation—FVC Test Result Reproducibility

As a goal during test result performance, the largest FVC and second largest FVC from acceptable curves should not vary by more than 5% of reading (expressed as a percentage of the largest observed FVC regardless of the curve on which it occurred) or 0.100 L, whichever is greater. In addition to the FVC criteria, the largest FEV_1 and the second largest FEV_1 (expressed as a percentage of the largest observed FEV_1 regardless of the curve on which it occurred) should not vary by more than 5% of reading or 0.100 L, whichever is greater.

The reproducibility criteria are used as a guide to whether more than 3 FVC maneuvers are needed; these criteria are *NOT* to be used for excluding results from reports or for excluding subjects from a study. Labeling results as being derived from data that do not conform to the reproducibility criteria stated above is encouraged (especially when the data suggests that bronchospasm was triggered by the FVC maneuver). The acceptability criteria should be applied before the reproducibility criteria (see figure 3). Unacceptable maneuvers should be discarded before applying the reproducibility criteria.

The only criterion for unacceptable subject performance, requiring elimination from further consideration, is less than 2 acceptable curves. No spirogram should be rejected solely on the basis of its poor reproducibility, provided 3 acceptable maneuvers were obtained. Reproducibility of results should be considered at the time of interpretation. Use of data from maneuvers with poor reproducibility is left to the discretion of the interpreter.

Rationale. It was not clear from the earlier ATS statement on standardization of spirometry, whether the 5% referred to FVC, FEV_1, or both FVC and FEV_1. Recent studies (48–50) have shown that the elimination of subjects for poor reproducibility may inappropriately eliminate subjects, resulting in a population bias. Pennock and associates have reported that subjects with airway obstruction have greater coefficients of variation than do normal subjects (68). Therefore, these subjects are more likely to be unable to meet the initial ATS minimum reproducibility criteria. In addition, the reproducibility should be changed to eliminate any confusion concerning which values are used and when the reproducibility criteria are applied. If acceptability criteria are not applied before the reproducibility criteria, then a passive exhalation maneuver may be labeled as the "best" maneuver if it gives the largest sum of FVC plus FEV_1.

The calculation of the FVC and FEV_1 reproducibility presents no problem for a computer; however, the need for rapid determination of FEV_1 during the testing session presents a recognized logistics problem if results are hand-measured and calculated.

VIII. REFERENCE VALUES AND INTERPRETATION STANDARDIZATION

This area of spirometry standardization is at an early stage in its development. The Intermountain Thoracic Society has recently published its Manual of Uniform Laboratory Procedures (17). The California Thoracic Society has published a similar book that emphasizes the controversy associated with selecting reference values and interpretation methodology (69).

Reference value determination is clearly an area of spirometry that must be further investigated and standardized. There are well over 20 reference value equations for spirometry in common use. Few data are available for several race and age groups. Although it is too early to standardize reference values, the committee recommends that, as a minimum, reference values for FVC and FEV_1 come from the same study so that they are internally consistent.

The standardization of interpretive procedures is also in need of further investigation (70). The present situation allows enough interpretive variability to cause identical data from a patient to be interpreted differently in different laboratories (71).

IX. CLINICAL ASSESSMENT

Clinical/Epidemiologic Considerations

Whether the spirogram results are to be used for clinical or epidemiologic purposes, the above recommendations apply.

Classification

The classification of spirometry into normal and abnormal groupings and into disease categories such as mild, moderate, and severe airway obstruction is simple, and is easily performed by a computer once criteria have been established. The meaning of such classifications requires clinical information. For example, the meaning of an FVC measurement that is just below the lower limit of normal is different in a young, healthy, nonsmoking individual than it is in a person who presents for evaluation of dyspnea or who has an abnormal chest radiograph. In the first case, the probability of a false positive test is large because the prior probability of disease is very low. In the second case, the probability of a true positive test is high because the symptoms and/or the abnormal radiograph increase the prior probability of disease. One area that causes considerable controversy is the combined obstruction and restriction classification. This classification is commonly made when airway obstruction is present; the problem is the FVC is reduced out of proportion to what was expected from the degree of obstruction. This problem may be more easily resolved when absolute lung volumes are available and approached in the context of the patient's clinical problems, and other clinical information such as a chest radiograph is available.

This statement was prepared by the Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. Members of the Committee were:

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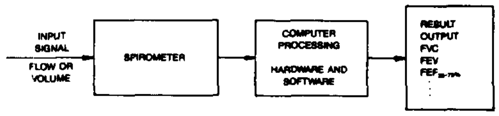


Fig. 4. Block diagram of spirometer data acquisition.

APPENDIX A – Signal Processing Tutorial

Since computers have come into such common use in spirometry and since fundamental errors have been detected in recently tested commercially available hardware and software (6), a short tutorial on signal processing is presented (figure 4).

For volume spirometers, signals are generally derived from electrical voltages from a potentiometer. Some spirometers also use optical shaft or position encoders (47). Flow devices of the Fleisch pneumotachometer variety also have electrical voltage outputs. For the volume spirometer with a potentiometer, and the flow device with a flow transducer, the signal is sampled by a computer's analog to digital (A to D) converter. The ability of these systems to accurately measure the spirogram depends on the volume or flow transducer's linearity, the accuracy and linearity of the electrical transducer (potentiometer), and the resolution of the A to D converter. A resolution of 12 bits (1 part in 4,096 – raw resolution of from 0.002 to 0.004 L) for the A to D is recommended, although 10 bits (1 part in 1,024 – raw resolution of from 0.008 to 0.016 L) may be adequate. The sampling rate of the spirometer volume or flow is very important. Lemen and associates (72) have shown that for both infants and adults, 95% of the signal energy in the flow-time of spirograms is within a bandwidth of zero to 12 Hz. For the volume-time curve, 95% of the signal energy is contained from zero to 6 Hz. Digital sampling theory requires that samples be taken at least twice the rate of the highest frequency contained in the signal (73). Thus for volume-time spirograms, a 12-Hz sampling rate should be adequate. However, most volume-time spirograms are sampled at a 100 Hz or greater rate to make measurements easier and more accurate. Figure 5 is a graphical illustration of time sampling of a volume-time spirogram. Computer system developers should be aware that even with 100-Hz sampling, it may be necessary to linearly interpolate between sampling points to determine accurate FEV_1, $FEF_{25-75\%}$, and other similar spirometric measures.

Volume sampling techniques with optical

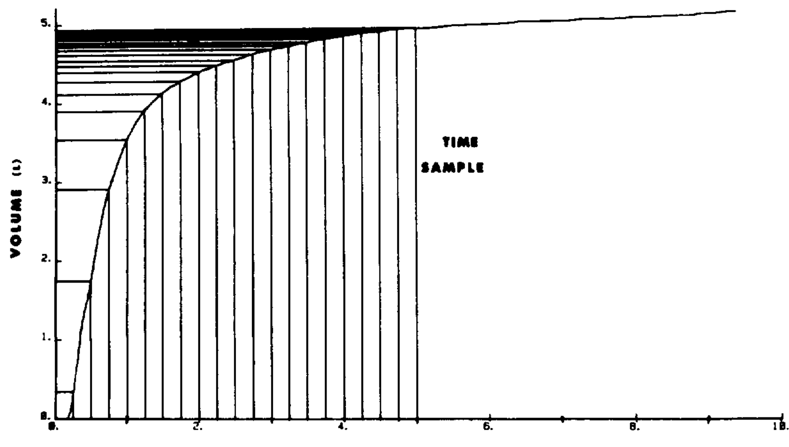


Fig. 5. Time-sampled spirogram.

and shaft or position encoders of the volume-time signal have been used (47). This approach measures the time interval between uniform volume intervals (for example, 0.010 L) as shown in figure 6. In this case, the resolution of time interval between measurements during rapid flow becomes a limiting factor. Ostler and associates have recently addressed these issues (47). For example, if a resolution of flow to within ± 5% of reading at 12 L/s for a system with 0.010-L resolution is required, then a clock resolution of at least 40 microsec is needed (47).

APPENDIX B—Standard Waveforms for Spirometer Validation

A recent study using the standard spirometry waveforms (6) described several ambiguities (areas for potential misinterpretation) in the values reported in terms of the revised ATS recommendations. The waveforms were initially obtained using an Ohio 840 spirometer (19). They were recorded on tape, then digitized with a 12-bit analog to digital (A to D) converter. The published results were then reported to the nearest 10 ml or 10 ml/s.

For clinical purposes, reporting of volumes to the nearest 10 ml is sufficient. At the time of the initial publication, it was felt that 10 ml accuracy of the standard waveform values would be sufficient for any use. Many spirometers at that time used only 10-bit A to D converters, providing a volume resolution of 6 ml for a 6-L spirometer. Because of the current availability of spirometers with 12-bit A to D converters and, consequently, better resolution, it became prudent to report all spirometry parameters to the nearest ml, decreasing the small errors that may occur because of rounding. Therefore, the original waveforms were reconverted from A to D units to volumes in ml and flows in ml/sec. In addition, all of the waveforms were extended to include no change in volume for 2.10 s following the last volume change (except 3, 4, and 17, which already stopped at 20.5 s). This satisfies the new spirometry end-of-test criteria for an "obvious plateau." The revised values for FVC and the other parameters are shown in table 4.

The changes from the published values for forced vital capacity (FVC) were primarily due to differences caused by round-off. However, several of the original waveform data files started with non-zero volume offset. The small offsets were a result of patients changing the amount of air in the spirometer by moving the patient hose before their expiration actually began. To avoid any ambiguities, these waveforms (Nos. 6, 7, 8, 11, 12, 15, 17, 21, 23) were modified by subtracting the small offset volume from all subsequent values in the data file. The largest difference was noted on Waveform 17, resulting in a decrease of 17 ml in the FVC. The other waveforms had offsets of either 1.5 or 3 ml.

The values for the FEV_1 were updated using interpolation between data points. The previous method found the zero time by back extrapolating from the highest flow, then counting 100 samples (1 s). Differences resulted because the back extrapolated time zero did not usually fall exactly at one of the sample times. The revised parameters calculated the exact time zero intercept on the time axis by linear interpolation, then calculated the FEV_1 by interpolating between points. The back extrapolated volume was also modified slightly because of the interpolation scheme used.

The FEF_{max} was unchanged since it was calculated as before, using a parabolic curve fitting routine to smooth the flow data. The parabolic curve fitting algorithm smoothed the data using a least squares parabolic fit to 80 millisec of the volume time curve. The formula used for the smoothing (74) was:

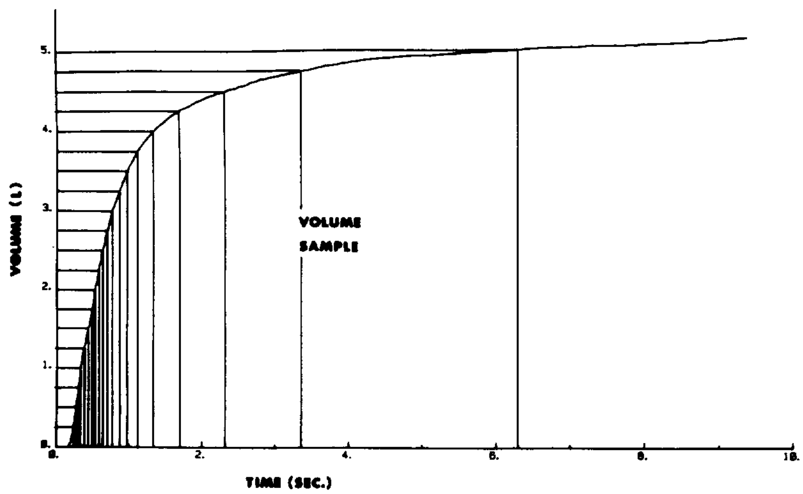


Fig. 6. Volume-sampled spirogram.

TABLE 3

SAMPLE POINTS VERSUS INTERPOLATED VALUES FOR 25% FVC AND 75% FVC

Point	Time (s)	Volume (L)	% FVC
A	0.28	1.442	24.3
	0.2839*	1.4843	25.0
B	0.29	1.549	26.1
C	0.77	4.449	74.9
	0.7711*	4.4528	75.0
D	0.78	4.479	75.4

$FEF_{25-75\%}$ USING CALCULATED VERSUS INTERPOLATED POINTS

Data Used	Calculated Flow
A–C	6.137
A–D	6.073
B–C	6.042
B–D	5.979
Interpolated	6.093

* Interpolated value.

TABLE 4

VALUES FOR STANDARD WAVEFORMS

Curve	FVC (*L*)	FEV_1 (*L*)	%FVC	V_{ext} (*L*)	%FVC	FEF_{max} (*L/s*)	$FEF_{25-75\%}$ (*L/s*)
1	6.000	4.262	71.0	0.052	0.9	6.497	3.410
2	4.999	4.574	91.5	0.068	1.4	9.873	5.683
3	3.498	1.188	32.0	0.014	0.4	1.380	0.644
4	1.498	1.371	91.5	0.019	1.3	2.952	1.704
5	5.132	3.868	75.4	0.087	1.7	7.535	3.209
6	4.011	3.027	75.5	0.317	7.9	5.063	2.572
7	3.169	2.519	79.5	0.354	11.2	4.750	2.368
8	1.993	1.615	81.0	0.151	7.6	3.450	1.857
9	4.854	3.772	77.7	0.203	4.2	7.778	3.365
10	3.843	3.031	78.9	0.244	6.3	4.650	2.899
11	2.735	1.811	66.2	0.022	0.8	3.708	1.272
12	2.002	1.621	81.0	0.094	4.7	3.807	1.780
13	4.896	3.834	78.3	0.460	9.4	5.207	3.677
14	3.786	3.053	80.6	0.338	10.2	4.368	3.122
15	5.937	5.304	89.3	0.080	1.3	12.132	6.092
16	5.458	3.896	71.4	0.215	3.9	7.395	2.892
17	5.833	2.597	44.5	0.035	0.6	5.257	1.153
18	4.343	3.155	72.6	0.042	1.0	7.523	2.335
19	3.935	2.512	63.8	0.044	1.1	5.408	1.137
20	2.881	2.563	89.0	0.041	1.4	5.822	2.695
21	4.477	3.549	79.3	0.102	2.3	9.398	3.368
22	3.857	2.813	72.9	0.036	0.9	5.055	2.204
23	3.419	1.360	39.8	0.013	0.4	2.868	0.531
24	1.237	0.922	74.5	0.037	3.0	2.095	0.709

V_{ext} = Extrapolated volume (see figure 2 for description).

$$y'(n) = \frac{\sum_{j=-4}^{4} j*y(n + jh)}{2* \sum_{j=1}^{4} j*j*h}$$

where h = the time between samples.

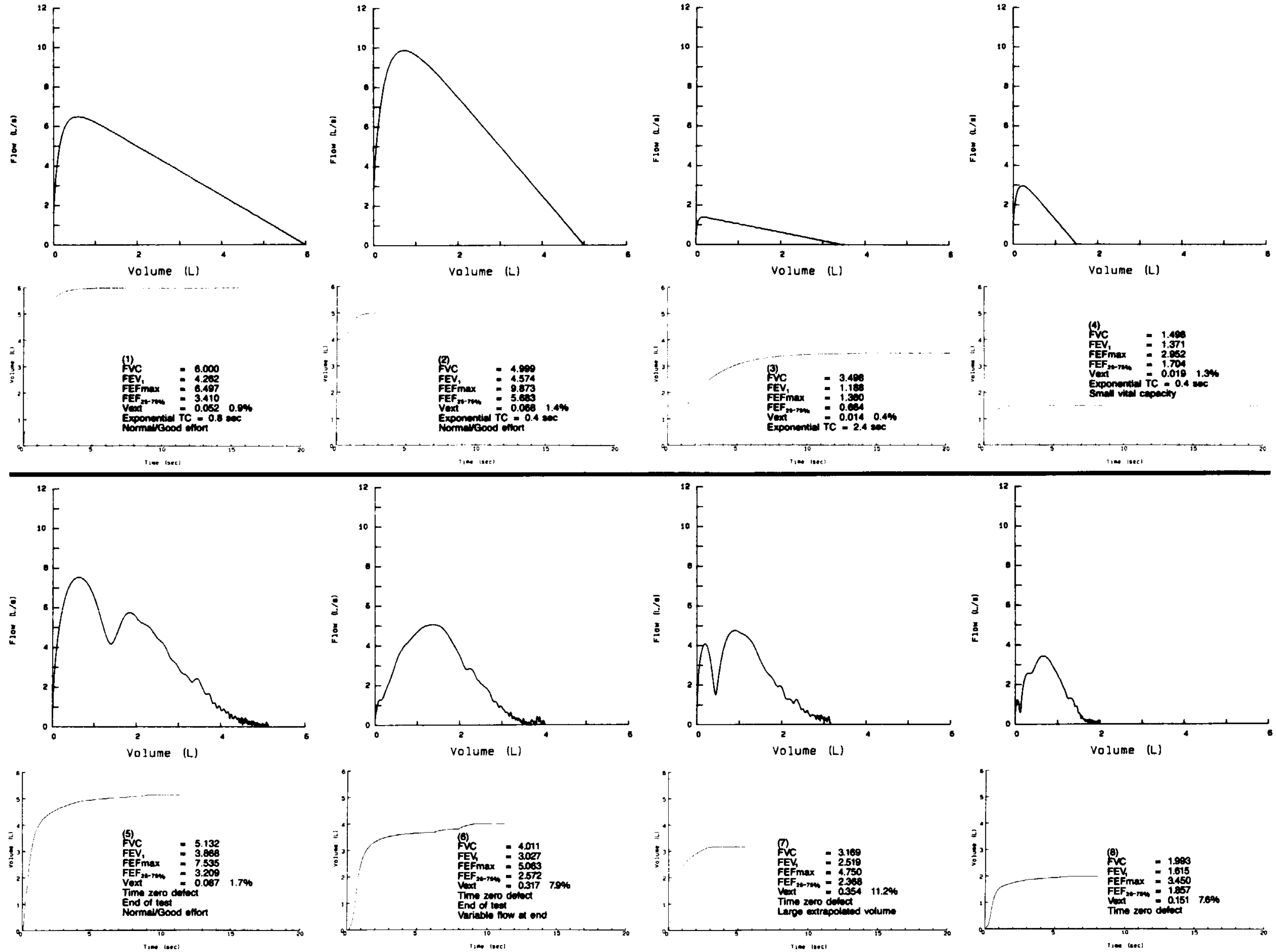
Calculating the $FEF_{25-75\%}$ from the digitized waveform data revealed a problem similar to that described for the FEV_1. When data points for 25% of the FVC and 75% of the FVC were not included in the file, these points had to be interpolated from the data points available. Errors as large as 5% were introduced into the calculation of $FEF_{25-75\%}$ when interpolation was not used (6). Table 3 illustrates the effect on Waveform 15.

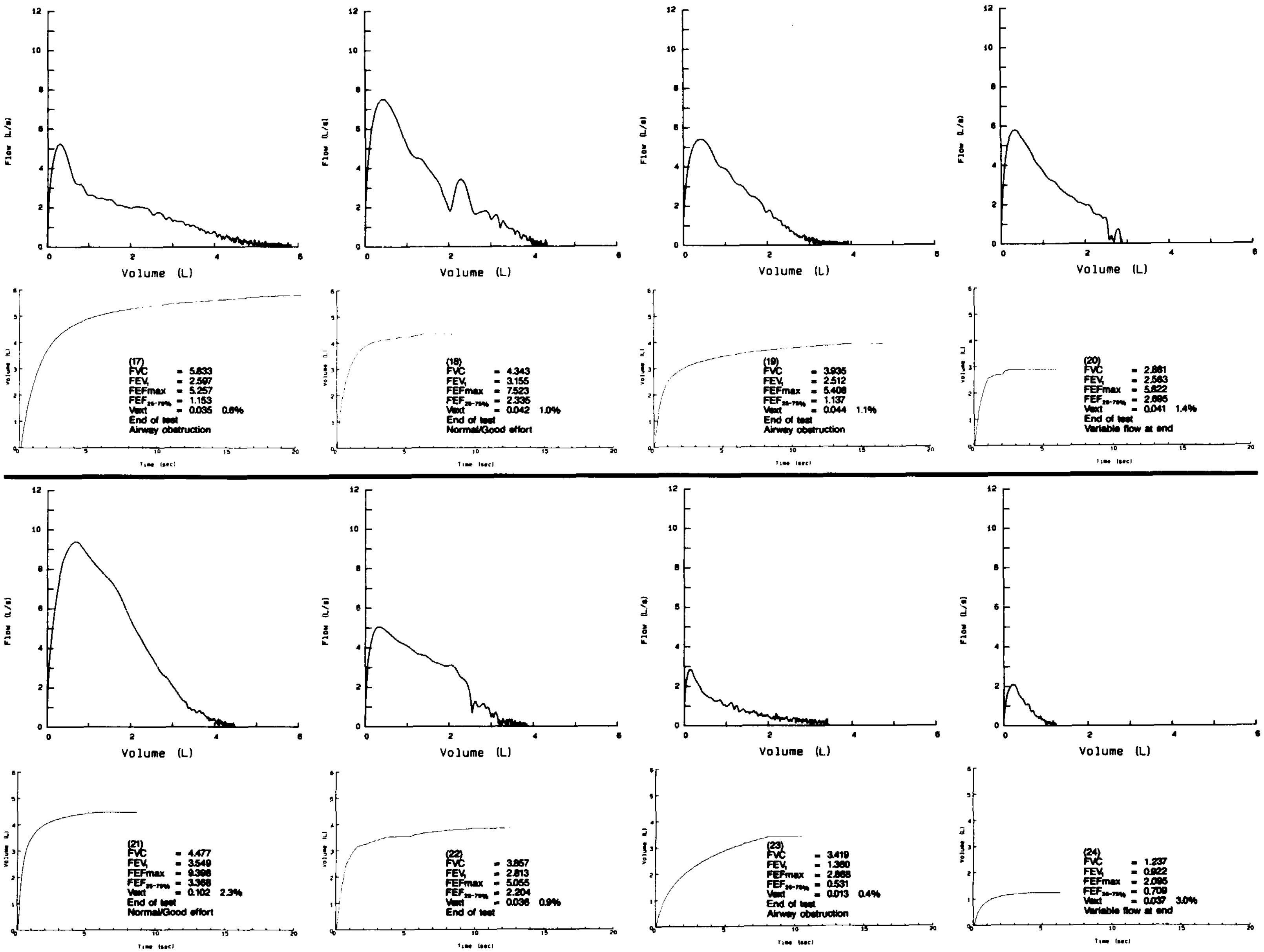
The forced expiratory time (FET) was defined as the time from time zero until the time of the last change in volume.

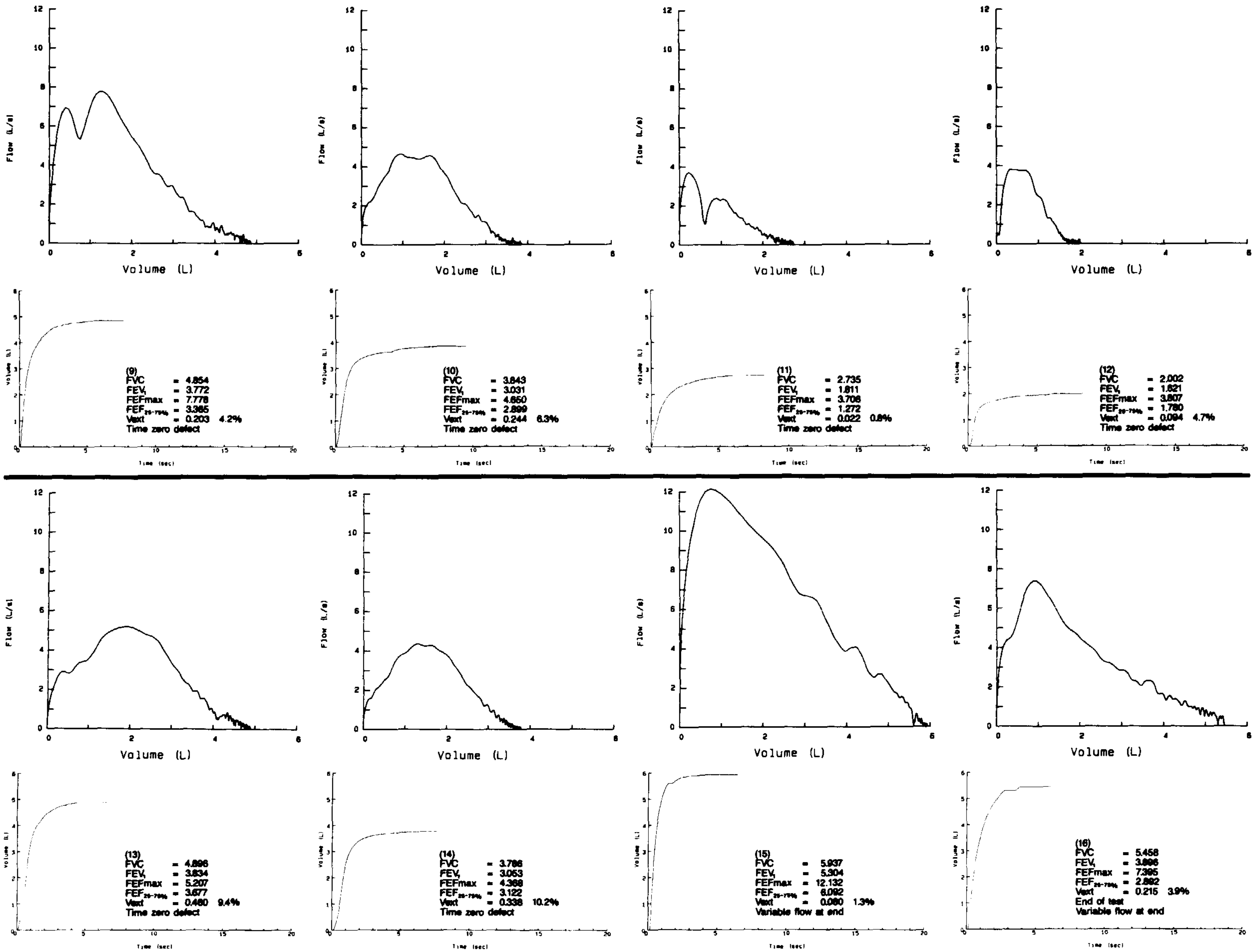
APPENDIX C—Standard Waveforms

Values for the standard waveforms are included as table 4. Plots of the volume-time and flow-volume curves for the 24 standard waveforms are also included.

(See following pages)


Flow (L/s)
Volume (L)
Volume (L)
Time (sec)
(1)
FVC = 6.000
FEV1 = 4.262
FEFmax = 6.497
FEF25-75% = 3.410
Vext = 0.052 0.9%
Exponential TC = 0.8 sec
Normal/Good effort
(2)
FVC = 4.999
FEV1 = 4.574
FEFmax = 9.873
FEF25-75% = 5.683
Vext = 0.068 1.4%
Exponential TC = 0.4 sec
Normal/Good effort
(3)
FVC = 3.498
FEV1 = 1.188
FEFmax = 1.380
FEF25-75% = 0.684
Vext = 0.014 0.4%
Exponential TC = 2.4 sec
(4)
FVC = 1.498
FEV1 = 1.371
FEFmax = 2.952
FEF25-75% = 1.704
Vext = 0.019 1.3%
Exponential TC = 0.4 sec
Small vital capacity
(5)
FVC = 5.132
FEV1 = 3.868
FEFmax = 7.535
FEF25-75% = 3.209
Vext = 0.087 1.7%
Time zero defect
End of test
Normal/Good effort
(6)
FVC = 4.011
FEV1 = 3.027
FEFmax = 5.063
FEF25-75% = 2.572
Vext = 0.317 7.9%
Time zero defect
End of test
Variable flow at end
(7)
FVC = 3.169
FEV1 = 2.519
FEFmax = 4.750
FEF25-75% = 2.368
Vext = 0.354 11.2%
Time zero defect
Large extrapolated volume
(8)
FVC = 1.993
FEV1 = 1.615
FEFmax = 3.450
FEF25-75% = 1.857
Vext = 0.151 7.6%
Time zero defect


Flow (L/s)
Volume (L)
Volume (L)
Time (sec)
(17)
FVC = 5.833
FEV1 = 2.597
FEFmax = 5.257
FEF25-75% = 1.153
Vext = 0.035 0.6%
End of test
Airway obstruction
(18)
FVC = 4.343
FEV1 = 3.155
FEFmax = 7.523
FEF25-75% = 2.335
Vext = 0.042 1.0%
End of test
Normal/Good effort
(19)
FVC = 3.935
FEV1 = 2.512
FEFmax = 5.408
FEF25-75% = 1.137
Vext = 0.044 1.1%
End of test
Airway obstruction
(20)
FVC = 2.881
FEV1 = 2.583
FEFmax = 5.822
FEF25-75% = 2.895
Vext = 0.041 1.4%
End of test
Variable flow at end
(21)
FVC = 4.477
FEV1 = 3.549
FEFmax = 9.398
FEF25-75% = 3.368
Vext = 0.102 2.3%
End of test
Normal/Good effort
(22)
FVC = 3.857
FEV1 = 2.813
FEFmax = 5.055
FEF25-75% = 2.204
Vext = 0.036 0.9%
End of test
(23)
FVC = 3.419
FEV1 = 1.360
FEFmax = 2.868
FEF25-75% = 0.531
Vext = 0.013 0.4%
End of test
Airway obstruction
(24)
FVC = 1.237
FEV1 = 0.922
FEFmax = 2.095
FEF25-75% = 0.709
Vext = 0.037 3.0%
Variable flow at end


Flow (L/s)
Volume (L)
Volume (L)
Time (sec)
(9)
FVC = 4.854
FEV1 = 3.772
FEFmax = 7.778
FEF25-75% = 3.365
Vext = 0.203 4.2%
Time zero defect
(10)
FVC = 3.843
FEV1 = 3.031
FEFmax = 4.650
FEF25-75% = 2.899
Vext = 0.244 6.3%
Time zero defect
(11)
FVC = 2.735
FEV1 = 1.811
FEFmax = 3.708
FEF25-75% = 1.272
Vext = 0.022 0.8%
Time zero defect
(12)
FVC = 2.002
FEV1 = 1.621
FEFmax = 3.807
FEF25-75% = 1.780
Vext = 0.094 4.7%
Time zero defect
(13)
FVC = 4.896
FEV1 = 3.834
FEFmax = 5.207
FEF25-75% = 3.677
Vext = 0.460 9.4%
Time zero defect
(14)
FVC = 3.786
FEV1 = 3.053
FEFmax = 4.368
FEF25-75% = 3.122
Vext = 0.338 10.2%
Time zero defect
(15)
FVC = 5.937
FEV1 = 5.304
FEFmax = 12.132
FEF25-75% = 6.092
Vext = 0.080 1.3%
Variable flow at end
(16)
FVC = 5.458
FEV1 = 3.896
FEFmax = 7.395
FEF25-75% = 2.892
Vext = 0.215 3.9%
End of test
Variable flow at end

APPENDIX D

SIC CODES AND INDUSTRIES INVOLVED WITH WELDING PROCESSES

The following list presents standard industrial classification (SIC) codes and industries involved with welding processes [OMB 1972].

Construction

1541 - General contractors--industrial buildings and warehouses
1542 - General contractors--nonresidential buildings, other than industrial buildings and warehouses
1622 - Bridge, tunnel, and elevated highway construction
1623 - Water, sewer, pipeline, communication, and power line construction
1629 - Heavy construction, not elsewhere classified
1711 - Plumbing, heating (except electric), and air conditioning
1761 - Roofing and sheet metal work
1791 - Structural steel erection

Services

7531 - Top and body repair shops
7539 - Automotive repair shops, not elsewhere classified
7699 - Repair shops and related services, not elsewhere classified

Manufacturing

3412 - Metal shipping barrels, drums, kegs, and pails
3433 - Heating equipment, except electric and warm air furnaces
3441 - Fabricated structural metal
3443 - Fabricated plate work (boiler shops)
3444 - Sheet metal work
3446 - Architectural and ornamental metal work
3448 - Prefabricated metal buildings and components
3499 - Miscellaneous metal work
3511 - Steam, gas, and hydraulic turbines and turbine generator set units
3523 - Farm machinery and equipment
3524 - Garden tractors and lawn and garden equipment
3531 - Construction machinery and equipment
3532 - Mining machinery and equipment, except oil field machinery and equipment
3533 - Oil field machinery and equipment
3534 - Elevators and moving stairways
3535 - Conveyors and conveying equipment
3536 - Hoists, industrial cranes, and monorail systems
3537 - Industrial trucks, tractors, trailers, and stackers

3541 - Machine tools, metal cutting types
3542 - Machine tools, metal forming types
3546 - Power driven hand tools
3547 - Rolling mill machinery and equipment
3549 - Metalworking machinery, not elsewhere classified
3551 - Food products machinery
3552 - Textile machinery
3553 - Woodworking machinery
3554 - Paper industries machinery
3555 - Printing trades machinery and equipment
3559 - Special industry machinery, not elsewhere classified
3561 - Pumps and pumping equipment
3563 - Air and gas compressors
3564 - Blowers and exhaust and ventilation fans
3567 - Industrial process furnaces and ovens
3569 - General industrial machinery and equipment, not elsewhere classified
3581 - Automatic merchandising machines
3582 - Commercial laundry, dry cleaning, and pressing machines
3585 - Air conditioning and warm air heating equipment, and commercial and industrial refrigeration equipment
3586 - Measuring and dispensing pumps
3589 - Service industry machines, not elsewhere classified
3599 - Machinery, except electrical, not elsewhere classified
3623 - Welding apparatus, electric
3711 - Motor vehicles and passenger car bodies
3713 - Truck and bus bodies
3714 - Motor vehicle parts and accessories
3715 - Truck trailers
3721 - Aircraft
3728 - Aircraft parts and auxiliary equipment, not elsewhere classified
3731 - Ship building and repairing
3732 - Boat building and repairing
3743 - Railroad equipment
3751 - Motorcycles, bicycles, and parts
3761 - Guided missiles and space vehicles
3769 - Guided missile and space vehicle parts and auxiliary equipment, not elsewhere classified
3792 - Travel trailers and campers
3795 - Tanks and tank components
3799 - Transportation equipment, not elsewhere classified

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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