

# Effects of Welding on Health, X



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**Key Words**— Welding, health, cancer, disease, exposure, fumes, gases, literature review, metal fume fever, noise, radiation, toxicology

# Effects of Welding on Health, X

Research performed by  
Biomedical Toxicology Associates  
Frederick, Maryland

Written by  
Winifred G. Palmer, Ph.D.  
and James C. Eaton, P.E.

Prepared for  
Safety and Health Committee

## Abstract

This literature review, with 293 citations, was prepared under contract to the American Welding Society for its Safety and Health Committee. The review deals with studies of the fumes, gases, radiation, and noise generated during various welding processes. Section 1 summarizes recent studies of occupational exposures, Section 2 contains information related to the human health effects, and Section 3 discusses the effects of welding on animals and cell cultures.



**American Welding Society**

550 N.W. LeJeune Road, Miami, Florida 33126



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\*Advisor

# Foreword

(This Foreword is not a part of *Effects of Welding on Health, X*, but is included for information purposes only.)

This literature review was prepared for the Safety and Health Committee of the American Welding Society to provide an assessment of current information concerning the effects of welding on health, as well as to aid in the formulation and design of research projects in this area, as part of an on going program sponsored by the Committee. Previous work consists of the reports Effects of Welding on Health I through IX each covering approximately 18 months to 2 years. Referenced materials are available from:

Biomedical Toxicology Associates  
6184 Viewsite Drive  
Frederick, MD 21701  
(301) 662-0783

# Comparative Listing—Welding Processes

*Explanatory Note:* Terms used in the technical literature sometimes do not correspond to those recommended by AWS in its publication ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

Accordingly, the following list may aid the reader in identifying the process in use.

| EWI—X                | Preferred AWS Term |                                                   |
|----------------------|--------------------|---------------------------------------------------|
| Gas or Flame Cutting | (OC)               | Oxygen Cutting or (OFC) Oxyfuel Gas Cutting       |
| Gas Welding          | (OFW)              | Oxyfuel Gas Welding or (OAW) Oxyacetylene Welding |
| MAG                  | (GMAW)             | — (with specified shielding gas)                  |
| MIG, GMA             | (GMAW)             | Gas Metal Arc Welding                             |
| MMA, SMA             | (SMAW)             | Shielded Metal Arc Welding                        |
| TIG                  | (GTAW)             | Gas Tungsten Arc Welding                          |
| Wire                 | Electrode          |                                                   |

## Glossary\*

|           |                                                           |
|-----------|-----------------------------------------------------------|
| AAS       | Atomic absorption spectroscopy                            |
| AB        | Asbestos body                                             |
| ACGIH     | American Conference of Governmental Industrial Hygienists |
| apo-D     | Apolipoprotein D                                          |
| ALA       | Delta-aminolevulinic acid                                 |
| BAL       | Bronchoalveolar lavage                                    |
| BiAL      | Biological Action Limit                                   |
| CAC-A     | Air carbon arc cutting or air-arc gouging                 |
| CI        | Confidence Interval                                       |
| Cr(III)   | Trivalent chromium                                        |
| Cr(VI)    | Hexavalent chromium                                       |
| CV        | Closing volume                                            |
| EDTA      | Ethylenediaminetetraacetate                               |
| EEG       | Electroencephalography                                    |
| EMF       | Electromagnetic field                                     |
| EMG       | Electromyograph                                           |
| FCAW      | Flux cored arc welding                                    |
| FGR       | Fume generation rate                                      |
| FSH       | Follicle stimulating hormone                              |
| FuCO      | Fractional uptake of CO                                   |
| GMAW      | Gas metal arc welding                                     |
| HPLC      | High-pressure liquid chromatography                       |
| HRCT      | High-resolution computed tomography                       |
| Hz        | Hertz                                                     |
| IgA       | ImmunoglobulinA                                           |
| IgM       | ImmunoglobulinM                                           |
| IL-1      | Interleukin-1                                             |
| IL-4      | Interleukin-4                                             |
| IL-6      | Interleukin-6                                             |
| IL-8      | Interleukin-8                                             |
| IR        | Infrared                                                  |
| Leukocyte | White blood cell                                          |
| LH        | Luteinizing hormone                                       |
| mRNA      | Messenger RNA (Messenger ribonucleic acid)                |
| MRI       | Magnetic resonance imaging                                |
| mT        | milliTesla                                                |
| NIOSH     | National Institute for Occupational Safety and Health     |
| OEL       | Occupational Exposure Limit                               |
| OR        | Odds ratio                                                |
| OSHA      | Occupational Safety and Health Administration             |
| PEL       | Permissible Exposure Limit                                |
| PMN       | Polymorphonuclear leukocyte                               |
| PMR       | Proportional mortality ratio                              |
| RADS      | Reactive airways dysfunction syndrome                     |
| RR        | Relative risk                                             |

\*Abbreviations for commonly used pulmonary function tests are found in Table 3.

|      |                                 |
|------|---------------------------------|
| SIR  | Standardized incident ratio     |
| SCE  | Sister chromatid exchange       |
| SMAW | Shielded metal arc welding      |
| SMR  | Standardized mortality ratio    |
| TLV  | Threshold Limit Value           |
| TNF  | Tumor necrosis factor           |
| TWA  | Time-weighted average           |
| UDS  | Unscheduled DNA synthesis       |
| UV   | Ultraviolet                     |
| VTG  | Volume of trapped gas           |
| VWF  | Vibration-induced white fingers |

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## Introduction

The health of workers in the welding environment is a major concern of the American Welding Society. To stay abreast of this subject, the health literature is periodically reviewed and published in the report *Effects of Welding on Health*. Nine volumes have been published to date; the first covered data published before 1978, while the remainder covered 1 to 2 year periods between 1978 and December 1991. The current report includes information published between January 1992 and December 1994. It should be read in conjunction with the previous volumes for a comprehensive treatment of the literature on the *Effects of Welding on Health*. Included in this volume are studies of the characteristics of welding emissions that may have an impact on the control technologies necessary to protect the welder (Section 1). In keeping with previous volumes, health reports and epidemiological studies of humans are discussed in Section 2, and organized according to the affected organ system. Research studies in animals and *in vitro* cell systems are discussed in Section 3.

Many of the studies on the effects of welding on health published during the current report period focused on matters that have been explored in the older literature. The question of whether or not welding causes a decrease in the function of the lungs or causes an increased incidence of pulmonary diseases such as asthma or bronchitis continues to be explored. As in the past, attention is focused on the incidence of lung cancer in welders and the contribution of the potential carcinogens nickel and chromium encountered in stainless steel welding to the incidence of the disease. Studies by Bonde et al. (Refs. 26–28) described in Volume 9 of the *Effects of Welding on Health*, raised concern about the possibility that welding might cause reproductive problems in male welders. Newer studies by these same authors have, for the most part, allayed these concerns and have also shown that the incidence of childhood malignancies and birth defects among children of welders lie within the normal range of the general population. We note that while considerable attention has focused over the years on the effects of welding on the male reproductive tract, only one study is known to have considered these effects in women welders (Ref. 210). Most studies of the effects of welding on health have excluded women, usually because the proportion of women in the welding population was too small to allow development of meaningful statistics. One way to address this important issue may be to examine the published literature concerned with the reproductive health of women with occupational exposures similar to those of welders.

An area of major interest is the contribution of the activity of alveolar macrophages, white blood cells which ingest inhaled particles, to disease processes in the lung. Activated macrophages produce proteolytic enzymes and oxidants which can help ward off invading microorganisms in the lung. However these protective substances are also capable of producing lung injury. Metal oxide particles can also elicit this response which explains, in part, why they may cause injury to the lung tissue. Metal oxide particles also induce macrophages to produce or synthesize proteins which can protect lung tissues from the deleterious materials produced by activated macrophages. Finally, the perennial question of the mechanism of metal fume fever is addressed. An interesting hypothesis propounded by Blanc et al. (Refs. 21 and 22) relates metal fume fever to cytokines or mediators released from macrophages that have been activated by ingestion of metal fumes particles.



## Executive Summary

### Effects on the Respiratory Tract

Pulmonary function tests are sensitive indicators of changes in the lungs and may be useful for diagnostic purposes in persons with pulmonary symptoms or for detection of early, minor changes in the lung that may still be reversible. Using these tests, deficits in air flow were detected in three studies in welders (Refs. 87, 185, and 223). Rossignol (Ref. 223) detected a decline in the FEV<sub>1</sub> of welders over a 5-year period. In 1985, Mur (Ref. 186) reported that the frequency of respiratory impairment was higher in welders than in other workers in the same factory. These differences between welders and non-welding controls persisted over a 5-year follow-up period (Ref. 185). Gennaro et al. (Ref. 87) observed a decline in FEV<sub>1</sub> and FVC among oxygas and arc welders compared with predicted values. Lung function measurements indicative of hyperreactivity in the small airways and possibly bronchitis or asthma were detected in welders by Nielsen et al. (Ref. 190) and Hjortsberg et al. (Ref. 114). In contrast to these results, Nakadate et al. (Ref. 188) found a significantly greater FEV<sub>1</sub> in welders compared with unexposed workers.

Three studies showed that transient changes in lung function may occur during the course of a single welding shift. Akbar-Khanzadeh (Ref. 2) found significant declines in FVC, lung transfer factor, and FEV<sub>1</sub> during the workshift among shipyard welders and non-welding controls. Both the number of workers who experienced a decline in lung function and the magnitude of the decline were significantly greater in welders than in non-welders. Welders who did not use any ventilation system showed a significant reduction in the lung transfer factor for CO, while welders who used a combination of local and general ventilation had no reduction in this factor. Dahlqvist et al. (Ref. 57) also found significant reductions in FVC and peak expiratory flow rate (PEFR) after a day of welding, but no changes in lung function occurred among welders who used a respirator. Donoghue et al. (Ref. 62) found a 5% decrease in PEFR at the end

of the first shift in a workweek among 50% of 20 welders compared with 5% of 20 non-welders.

Coggon et al. (Ref. 46) analyzed occupational mortality data from Great Britain and found a significantly increased mortality from pneumonia among welders. He concluded that lobar pneumonia should be classified as an occupational disease in welders. Kennedy (Ref. 143) disputed this association, and noted that the excess occurrence of pneumonia may have been the result of a combination of increased susceptibility and increased exposure potential in the metal trades. She suggested that it would be more prudent to study pneumonia as a potential occupational disease in the metal trades in general. Kennedy pointed out the need for proper use of the label “occupational disease” because of its far-reaching consequences to the patient and the public whereby an association between occupation and disease may influence changes in employment, compensation costs, and the adoption and/or installation of controls to limit exposure.

Two case reports discussed in this volume of *The Effects of Welding on Health* further demonstrate the importance of investigating occupational history and confounding exposures before attributing disease conditions to exposures particular to a specific occupation. In the first, Glass et al. (Ref. 91) attributed a case of chronic interstitial lung disease in a 32-year-old welder to his 8 years employment performing GMAW of galvanized steel in a poorly ventilated work area. While Glass et al. noted that the welder had been employed in a job where he repaired and spray painted fiberglass boats between the ages of 28 and 32, they passed over any contribution that conditions in the latter work situation may have made to the development of his restrictive lung disease.

The second example, described by Levin (Ref. 159), is the case of a shipyard welder who died of mesothelioma. This condition, which is almost always associated with exposure to airborne asbestos, was, at first, largely attributed to his welding experience in a shipyard during World War II. Careful investigation by Levin revealed that the deceased patient had also worked as a laundromat operator for 15 years during which time he had

frequently repaired washing machine clutch linings which were confirmed by the manufacturer to have contained 10 to 12% chrysotile asbestos. This case report clearly demonstrates the necessity for examining the patient's complete occupational history before ascribing a disease condition to any single occupational exposure.

## Cancer

**Lung Cancer.** In 1993, Commission VIII of the International Institute of Welding concluded that welders as a group have a slightly greater risk of developing lung cancer than the general population (Ref. 290). The contribution of smoking and asbestos exposure to the excess cancer risk detected in the many epidemiologic studies of welders is unknown but probably does not totally account for the elevated risk. Sjogren (Ref. 239) combined data from five studies that had controlled for smoking and asbestos and found a significant relationship between lung cancer and welding of stainless steel when these two important confounders were taken into account.

Three new epidemiologic studies of the incidence of lung cancer among welders controlled for exposure to asbestos and smoking. Danielson et al. (Ref. 58) found an elevated cancer incidence among welders in a Norwegian shipyard. Moulin et al. (Ref. 183) found a significant excess of lung cancer deaths in mild steel welders but not in stainless steel welders. In a case-control study, Jockel et al. (Ref. 134) also observed an increased risk for lung cancer among welders, but the risk was not significantly different from that of controls after correction for smoking and asbestos exposure. A statistically significant excess of lung cancer deaths was observed among welders in studies conducted by Firth et al. (Ref. 73) and Keller and Howe (Ref. 142). These studies did not control for smoking or asbestos exposure.

Wu-Williams et al. (Ref. 283) conducted a case-control study of occupationally related lung cancer among women in northern China, where there is a considerable population of women in the industrial workforce. A significant excess risk for lung cancer was not found among the welders.

**Cancer in Organs Other Than the Lung.** In a case-control study of sino-nasal cancer in France, Luce et al. (Ref. 162) found no association between exposure to welding fumes and any form of sino-nasal cancer. Welding was also not found to be a risk factor in any of three epidemiologic studies of bladder cancer (Refs. 48, 142, and 284). Persson et al. (Ref. 206) found a marginally significant increase in the risk for non-Hodgkin's lymphoma, but not in the risk for Hodgkin's disease, among

welders. Kauppinen et al. (Ref. 141) examined all cases of primary liver cancer reported during a 4-year period in Finland and found a significantly increased risk for this disease among welders exposed to fume concentrations of 2.5 mg/m<sup>3</sup> for ten or more years. The investigators recognized that this association had not been made before and indicated that further studies should be conducted to test these observations. Finally, two case-control studies (Refs. 45 and 214) failed to establish a link between welding-associated EMFs and leukemia.

## Effects on Fertility

Bonde and Ernst (Ref. 32) examined semen quality in 30 welders who performed GTAW of stainless steel, 30 welders who performed SMAW or GMAW of mild steel, and 47 controls. There was no correlation between chromium levels in blood or urine and deterioration of any of the semen parameters tested or concentrations of follicle stimulating hormone and luteinizing hormone in blood. In another study by Bonde et al. (Ref. 34), an association between the incidence of spontaneous abortion among the wives of stainless steel, but not mild steel, welders was observed. The data on spontaneous abortions were reexamined and, in 1995, Bonde and associates (Ref. 113) published a report retracting their earlier findings (Ref. 34). The new data showed that there was no increase in the occurrence of spontaneous abortions among wives of welders. Bonde et al. (Ref. 34) also found that the incidence of malignant disease in children of welders was very close to national rates of malignancies in children. The overall occurrence of congenital malformations was actually lower than expected in children of welders. This difference was significant for children whose fathers were mild steel welders.

In a population-based case-control study, Schnitzer et al. (1994) examined whether or not there are associations between birth defects and several paternal occupations. Welders were not found to have offspring with a significantly increased incidence of birth defects.

## The Alveolar Macrophage

Several investigations focused on the role of the alveolar macrophage in disease processes that could result from inhalation of welding fumes and other particles. Alveolar macrophages represent the first line of defense against foreign particles (such as pathogenic microorganisms) in the lungs but their activity may also contribute to disease processes. Once inhaled, foreign particles are

ingested or phagocytosed by macrophages. Macrophages activated by phagocytosis release cytokines and other mediators, some of which attract immune and inflammatory cells into the area and also induce the growth of fibroblasts which can eventually cause scar tissue (fibrosis) to form in the lungs. Activated macrophages also release hydrolytic enzymes and proteases (enzymes that break down proteins) and other substances which may cause tissue damage.

**Antioxidants.** Activated macrophages also produce the strong oxidants, peroxide and superoxide. While the release of oxidants may play an important role in the destruction of foreign bodies such as bacteria, oxidants can also cause the oxidation of cellular macromolecules (e.g., proteins, lipids and DNA) and may, thereby, contribute to pathological processes in the lungs. Some components of welding emissions (e.g., ozone and oxides of nitrogen), may also cause injury by acting as oxidants in biological systems.

Lipid peroxidation has been the theme of work in progress for several years in the laboratory of Geleskul et al. (Refs. 82–84). In the past, these investigators have shown that instilling welding fumes into the lungs of laboratory rats can cause peroxidation of lipids in the lungs and liver. Recent work from this laboratory (Refs. 79 and 80) demonstrated that treatment with antioxidant vitamins (vitamins A, C, and E) before or after administration of welding fumes can markedly inhibit the oxidation of lipids.

Cellular and extracellular enzymes that act as antioxidants such as superoxide dismutase, catalase, and glutathione peroxidase, exist naturally in the body and afford some protection against the damaging effects of oxidants. Mongiat (Ref. 178) found that the concentration of ceruloplasmin, a serum protein with antioxidant activity, was significantly elevated in smoking welders compared with nonsmoking welders and smoking and nonsmoking controls. He conjectured that increases in serum ceruloplasmin levels may represent an adaptive mechanism against the combined effects of oxidants in welding fumes and cigarette smoke.

**Metal Fume Fever.** Blanc et al. postulated that cytokines released from activated macrophages and other leukocytes activated by inhaled metal oxide particles are responsible for the systemic, flu-like symptoms characteristic of metal fume fever. Their hypothesis was strengthened by the demonstration that the cytokines tumor necrosis factor (TNF), interleukin-6, and interleukin-8 become elevated in bronchoalveolar lavage fluid obtained from 23 welders after exposure to fumes generated by welding galvanized mild steel (Refs. 21 and 22). The investigators concluded that a network of cytokines, released from activated alveolar macrophages following

the phagocytosis of metal oxide particles, is involved in the pathogenesis of metal fume fever. Further work is necessary to firmly establish this well-founded idea.

**Induction of Protein Synthesis.** The synthesis of some proteins can be triggered or induced by chemicals or substances that are not ordinarily present in the cell or its environment. Wiethege (Ref. 282) showed that welding fumes can induce the synthesis of the cytokine TNF by alveolar macrophages. Other investigators showed that welding fumes or zinc oxide particles can induce the synthesis of proteins that have a protective effect against hydrolytic enzymes or oxidants released from macrophages or from the toxic effect of metals themselves. Ossege (Ref. 193) showed that synthesis by alveolar macrophages of alpha-2-macroglobulin, a protease inhibitor, is induced by welding fumes. Cosma et al. (Ref. 49) showed that inhalation of zinc oxide particles causes the induction of metallothionein and heme oxygenase in lung tissue. Heme oxygenase is thought to be involved in the natural defenses of the body by scavenging free radicals (e.g., superoxide). Metallothioneins are proteins that strongly bind metals such as zinc, copper, cadmium, and mercury. The sequestration of metals by metallothionein is thought to protect cells from the effects of toxic metals.

**Summary.** Inhaled metal oxide particles induce alveolar macrophages to synthesize metallothionein, heme oxygenase, the cytokine TNF and possibly other mediators. Cytokines released from macrophages attract other cells essential to the inflammatory process into the area and, as suggested by the work of Blanc (Refs. 21–23), may also cause the flu-like symptoms typical of metal fume fever. The heightened levels of alpha-2-macroglobulin and heme oxygenase induced by metal oxide particles would afford some protection of the surrounding tissues from the effects of proteases and oxidants also produced by macrophages. Finally, the heightened levels of metallothionein, also induced by metal oxide particles, may afford protection against metal toxicity. If the levels of metallothionein become further increased with successive exposures to metal oxide particles, then the efficiency of the sequestration of metal particles could possibly increase with successive exposures, providing more and more protection against the effects of toxic metals. While such a phenomenon has not been shown for welding fume particles, Squibb et al. (Ref. 244) showed that the metallothionein levels following exposure to cadmium, are higher in animals that had been previously exposed to cadmium than they are in animals with no prior exposure to cadmium. Assuming that secondary exposures to other metal oxides more typical of welding fumes will also lead to higher metallothionein levels than the first exposure, it can be postulated that the tolerance to welding fumes that develops through the

workweek is related to increasingly higher levels of metallothionein in the lungs. Assuming further that metallothionein levels decrease to normal following a weekend break in welding activities, the protective effects of metallothionein would no longer be present at the start of the

workweek, and an individual could once again be susceptible to the systemic effects developing from exposure to metal oxide fumes. This would explain why metal fume fever most frequently occurs on Monday, after a weekend break from exposure to welding fumes.

## Technical Summary

### *The Exposure*

#### Fume Composition

The effects of modifying constituents of flux cored electrodes on the concentrations of metal components in welding fumes were examined by Hewitt and Hirst (Ref. 109). The fume generation rate (FGR) was unaffected by the content of either rutile or basic slag formers. The Fe, Cr, and Ni content of the fume decreased as the rutile content of the electrode increased but the Mn content of the fumes increased as the rutile content increased from 2% to 10%. With basic-cored wires, the content of all of the metals tested, including Mn, decreased in the fumes as the content of the slag former increased.

Jin (Ref. 133) measured particle size distributions in gas metal arc welding fumes collected in a large, test chamber using mild steel electrodes of three different diameters. The FGR was best correlated with arc power. In a study of the emissions from braze welding of steel to brass, Beauflis (Ref. 14) showed that the emission of all of the metallic pollutants, especially zinc, increased with the welding temperature.

#### Analytical Methods

Swamy et al. (Ref. 255) described a wavelength-dispersive X-ray fluorescence method for determining the chemical composition of welding fumes collected on glass-fiber filter. Iqbal et al. (Ref. 128) used neutron activation analysis to determine the concentrations of trace elements in welding fumes generated in the breathing zone during gas metal arc welding (GMAW) of mild steel. The air concentrations of all the elements measured were consistently higher when they were derived from samples collected on glass-fiber filters compared with concentrations derived from samples collected on cellulose filters.

**Chromium.** Spini (Ref. 243) described a method for analysis of chromium in welding fumes based on selective solubilization of elemental chromium, trivalent chromium Cr(III), and hexavalent chromium Cr(VI). Sheehan (Ref. 232) used a modified impingement method in order to collect air samples that were sufficiently large to permit the analysis of very low concentrations of Cr(VI) in air. Using a Sputnic air sampling unit, Dyg et al. (Ref. 63) developed a technique for producing multiple filters homogeneously loaded with welding fumes and containing identical quantities of Cr(VI). The purpose of this work was to design reference materials for use as controls in an international laboratory study directed at validating state-of-the-art techniques for chromium speciation in welding fumes.

**Fluoride.** Vasconcelos et al. (Ref. 271) developed a solid-phase extraction/ion chromatography procedure for determining fluoride in welding fumes.

**Nickel.** Nickel concentrations are routinely measured in welding fumes by atomic absorption spectrometry (AAS). Hernandez-Lopez (Ref. 108) showed that the speed and sensitivity of this method could be greatly increased by complexing nickel in welding fumes with 2-benzyl-2-pyridylketone-2-pyridylhydrazine followed by extraction with methyl isobutyl ketone.

**Analysis of Metals in Biological Fluids.** Christensen et al. (Ref. 43) developed a method using Zeeman AAS, to determine chromium levels in blood and urine. Blood and serum samples were pretreated with subtilisin, a proteolytic enzyme, to solubilize blood proteins prior to analysis. Tomokuni et al. (Ref. 258) developed a method using a fluorometric high-pressure liquid chromatography (HPLC) to measure delta-aminolevulinic acid in human serum or plasma. Pan and Huang (Ref. 198) developed a method using mercury/hydride and cold vapor AAS to measure concentrations of arsenic and mercury in urine.

**Air Monitoring.** Dust loss due to bypass leakage during the sampling of welding fumes with filter cassettes could

lead to an underestimation of a worker's total aerosol exposure. Van der Heever (Ref. 267) established procedures for testing internal leakage in filter cassettes.

## Workplace Exposures

The cause of excessive lead concentrations measured in the breathing zone of welders during air carbon arc cutting inside vessels at an oil refinery was investigated by Harris and Carter (Ref. 104). The source of the lead was traced to the copper-clad carbon electrodes.

Karlsen et al. (Ref. 139) showed that the contents of Mn and total Cr were lower in grinding dust than in welding fumes and that hexavalent chromium, which was present in concentrations of 300  $\mu\text{g}/\text{m}^3$  in welding fumes, was undetectable in grinding dust. Samples collected in welding shops, where grinding and welding were concurrent, contained about 30% less Cr(VI) than did welding fume samples collected in the absence of grinding, presumably due to dilution of the welding fumes by grinding dust. As part of a joint Norwegian-German study sponsored by the World Health Organization, Karlsen et al. (Ref. 140) monitored the concentrations of total dust, Ni, Cr, Cr(VI), and Mn in air samples collected during shielded metal arc welding (SMAW) of stainless steel in three types of worksites. In general, Cr(VI) comprised about 50% by weight of the total Cr. In agreement with their earlier findings (Ref. 139), Cr(VI) was undetectable in a workshop where the surfaces of stainless steel sinks were ground and polished in the absence of ventilation.

Matczak and Chmielnicka (Ref. 168) determined concentrations of total and respirable particles, Fe, Mn, Ni, F, total Cr, Cr(VI), and Cr(III) in 120 fume samples collected in the breathing zones of welders during SMAW of stainless steel in four Polish plants. Hlavay et al. (Ref. 115) analyzed fumes collected in the breathing zones of seven welders from Hungarian metalworking shops. The mean respirable dust concentration was 5.52  $\text{mg}/\text{m}^3$ , and accounted for 58% of the mass of the breathing zone samples.

Using two large databases maintained by the Regional Institutes of Occupational Health in Finland, Kiilunen (Ref. 146) evaluated workers' exposure to Ni and Cr during the years 1980 through 1989. For welders, the mean air concentrations of total Cr, Cr(VI), and Ni exceeded the Finnish Occupational Exposure Limits. Most of the urinary Cr and Ni concentrations measured among the welders were below the Finnish Biological Action Limits.

When a biological monitoring program in an Italian power plant showed that urinary nickel levels were sub-

stantially elevated in welders, some adjustments in personal prevention measures were introduced at the workplace. Subsequent tests of metal concentrations in urine, conducted by Carrer et al. (Ref. 39), indicated a progressive reduction in urinary nickel excretion levels in all welders.

## Welding with Lasers

Hietanen et al. (Ref. 111) evaluated radiation and chemical hazards associated with CO<sub>2</sub> lasers. Their results indicated that diffuse reflection of the laser beam was small during normal operations. However, substantial scattered radiation resulted from a misdirected beam. Haferkamp et al. (Ref. 99) investigated the rates of aerosol and slag emissions from metal cutting with a 1-kW laser and welding with a 5-kW laser.

**Hazards Associated with Lasers.** Johnson (Ref. 136) described a database of 221 accidents reported to a major American laser manufacturer. The eye was the most frequently injured organ, accounting for 61% of the injuries. Skin injuries accounted for 10% of the reported injuries.

## Electromagnetic Fields

Bracken (Ref. 37) described a study sponsored by the Electric Power Research Institute (Ref. 36) in which an arc welder was fitted with a meter that continuously monitored and recorded his exposure to low-frequency electromagnetic fields (EMFs) throughout the workday. While his median exposure to EMFs was 0.7  $\mu\text{T}$ , peak exposures exceeded 10  $\mu\text{T}$ , and exposures greater than 5  $\mu\text{T}$  were encountered during 5% of the day. Szuba (Ref. 256) calculated steady-state EMFs generated by welding and verified them with laboratory measurements.

Melton (Ref. 172) discussed EMFs from welding equipment in light of a European Directive designed to eliminate electromagnetic interference with electronic equipment. The emissions produced during high-frequency arc initiation in gas tungsten arc welding (GTAW) are about 10 000 times the maximum permitted levels in the proposed industrial standard.

Marco et al. (Ref. 164) evaluated the effect of EMFs from welding on the operation of cardiac pacemakers. GTAW and submerged arc welding machines up to 1000 A were judged to be safe for workers with pacemakers who were no closer than 1 meter from the weld. Embil et al. (Ref. 65) described the case of a welder who returned to arc welding following implantation of a cardiac defibrillator.

## Incidental Exposures

**Production Coatings.** Berger (Ref. 18) measured the pollutants generated from spot welding of oil-coated steel sheets. Oil mist concentrations ranged from 0.10 to 0.24 mg/m<sup>3</sup> for spot welding in automatic lines and from 0.16 to 0.80 mg/m<sup>3</sup> when using a spot welding gun.

**Thermal Exposure.** Ambient temperatures during welding in a brassware factory in Morabadad, India, averaged 41.1°C, as measured by Rastogi et al. (Ref. 212). The globe temperature averaged 50.3°C.

## Hygiene and Work Practices

**Training.** The PIMEX system, which couples video taping of workers with direct-reading instrumentation of breathing zone exposures was recently used to evaluate the effectiveness of local exhaust systems which had been installed at every workstation in a factory in an attempt to reduce the exposures of 30 welders to Cr(VI). Using the PIMEX system, it was found that the exposure to welding fumes was still high for some of the welders after the installation of local exhaust equipment because they failed to use the equipment properly (Refs. 219 and 220).

**Ventilation.** Nygren and Nordstrom (Ref. 191) measured air quality in two Swedish welding workshops before and after energy-conserving changes in local ventilation were made that activated supply and exhaust ventilation only when welding was being performed. A general reduction in dust concentrations was achieved by the plant modifications.

**Protective Gear and Equipment.** Sutter (Ref. 252) discussed the specifications for welding screens and curtains to protect non-welders and passersby from ultraviolet (UV) and infrared radiation. Sutter and Ott (Refs. 253 and 254) investigated the temperature increase in eye-protective filters during welding. High-grade silver and gold coatings were found to provide effective protection against thermal buildup in the filter, while coatings of other materials are not a worthwhile improvement over unclad filters.

**Accidents.** Suruda and Smith (Ref. 251) reported that there were 33 electrocution deaths involving portable arc welding equipment in the databases of the National Institute for Occupational Safety and Health, and the Occupational Safety and Health Administration (OSHA) for the years 1984 through 1986. The details of fatal accidents occurring to ironworkers during steel building and plant construction in the U.S. were examined by Hardesty et al. (Ref. 103). Between 1985 to 1989, 44 fatalities that resulted from falls occurred during welding or bolt-up

operations. Davie et al. (Ref. 60) discussed 73 accidents that occurred in heated bitumen storage tanks in the United Kingdom during the years 1971 through 1992. Nine of the cases occurred during welding or using a blow torch to heat a plugged line.

## *Effects of Welding on Human Health*

### Respiratory Tract

**Pulmonary Function.** Chinn (Ref. 41) showed that pre-employment tests performed in the late teenage years could be used as baseline values for monitoring changes in lung function in adults, although tests performed after the welder's twenty-first birthday were more valuable for this purpose. Mur et al. (Ref. 185) reexamined workers from an industrial trailer factory who had participated in a study reported in 1985 (Ref. 186). They found that welders continued to have a greater frequency of respiratory impairment than other workers, however, the magnitude of the differences between welders and controls did not change significantly during the 5-year period between examinations. Nielsen et al. (Ref. 190) studied lung function in a group of aluminum welders using GMAW and stainless steel welders using SMAW. There were no differences in spirometry measurements between welders and controls, but lung function tests after administration of methacholine showed changes indicative of small airways inflammation among the welders. These changes increased with welding experience. In a lung function study conducted by Nakadate et al. (Ref. 188), significantly greater forced expiratory flow rates and forced expiratory volumes were found in welders than in asbestos workers or unexposed workers. Gennaro et al. (Ref. 87) compared FEV<sub>1</sub> and FVC measurements among oxygas and arc welders with predicted values based on the subjects' heights and weights. Their analysis showed significantly increased restrictive lung disease among both groups of welders. Rossignol (Ref. 223) detected a decline in the FEV<sub>1</sub> and FEV<sub>1</sub>/FVC of 229 welders over a 5-year period. Hjortsberg et al. (Ref. 114) studied lung function in nonsmoking, nonatopic welders and controls. The major finding was a significant increase among the welders in the volume of trapped gas, a sensitive indicator of asthma.

Three groups of investigators showed that transient changes in lung function may occur during the course of a single welding shift. Akbar-Khanzadeh (Ref. 2) found significant declines in FVC, lung transfer factor, and FEV<sub>1</sub> during the workshift among shipyard welders and

non-welding controls. The number of subjects exhibiting a decline in lung function and the magnitude of the decline were significantly greater among the welders than controls. Dahlqvist et al. (Ref. 57) also found significant reductions in FVC and peak expiratory flow rate (PEFR) after a day's welding, but no reduction was found among welders who used a particulate respirator. Donoghue et al. (Ref. 62) observed a 5% decrease in PEFR at the end of the first shift in a workweek among 50% of 20 welders compared with 5% of 20 non-welders.

**Asthma and Bronchitis.** Wanders et al. (Ref. 275) found a significantly increased incidence of respiratory disease among shipyard welders in a study that was aimed primarily at linking musculoskeletal disease to welding. In a postal survey of 7582 male metal workers, Hansen and Skytthe (Ref. 102) found that exposure to welding fumes and metal grinding dust was significantly associated with chronic bronchitis and asthma. In a study of asthma in identical twins, Antti-Poika et al. (Ref. 10) found no relationship between asthma and welding in general or welding of various metals. In a study of sheet metal workers exposed to fiberglass and asbestos, Hunting and Welch (Ref. 123) found a significant correlation between four or more years of welding exposure and development of obstructive lung disease.

Wang et al. (Ref. 276) found a higher incidence of asthma among former and active welders of mild and stainless steel than among non-welding controls. As part of a project entitled the "surveillance of work-related and occupational respiratory disease" (SWORD), specialists in occupational and thoracic medicine have been reporting newly diagnosed cases of work-related respiratory disease in the United Kingdom on a regular basis since 1989 (Ref. 175). Occupational asthma represented 1085 of the 4229 cases of work-related respiratory disease reported to the SWORD project between 1989 and 1990 (Ref. 174). Three cases of occupational asthma (0.3%) were identified in workers exposed to stainless steel welding fumes and 20 (1.8%) were identified in workers exposed to other welding fumes during that period. Of 395 asthma cases reported to the SWORD project in 1993, eight (2%) were reported to have occurred in welders. Of these, one reported exposure to aluminum, three to steel, one to hard metal, and three reported exposures to welding or foundry fumes. (Ref. 225). Welding was reported by Canadian physicians as the suspected cause for four out of 124 cases of occupationally related asthma in a study by Contreras et al. (Ref. 47). Boulet et al. (Ref. 35) studied eleven patients with occupational asthma, two of whom were welders. They found decreases in FEV<sub>1</sub> and also marked inflammatory changes in lung biopsy tissue compared with normal controls.

**Pneumonia.** In an analysis of occupational mortality data from England and Wales, Coggon et al. (Ref. 46) found significantly increased mortality from pneumonia among welders, but not among retired welders. They stated that lobar pneumonia should be classified as an occupational disease in welders. Kennedy (Ref. 143) disputed this association, and suggested that it would be more prudent to study the disease as a potential occupational disease in the metal trades in general.

**Pneumoconiosis.** Marek and Starzynski (Ref. 165) found that approximately 17% of all occupational diseases reported in Poland during the years 1961 to 1992 were pneumoconioses. Arc welders' pneumoconiosis was the third most prevalent form of pneumoconiosis and appeared in 0.7 of every 100 000 workers. Shmutter (Ref. 233) found elevated levels of immunoglobulins and active lymphocytes among pneumoconiosis patients, some of whom were welders. Hasegawa and Sakamoto (Ref. 105) described a case of siderosis in a welder who was free of symptoms, even though X-rays showed massive involvement in the lungs.

**Asbestosis.** Klaas (Ref. 148) examined 75 subjects, including shipyard welders, who had been exposed for an average of 23 years to asbestos. Clinical asbestosis was found in 16 individuals by listening for the presence of rales, and by subjecting them to lung function tests and chest X-rays. Two newer techniques, high-resolution computed tomography and gallium scanning, detected more cases of asbestosis than did the standard clinical techniques. The author proposed that these two noninvasive techniques could be used as early indicators of the development of asbestosis.

**Case Reports.** Inoue et al. (Ref. 127) described a case of suspected acute cadmium poisoning in a man who had been brazing copper pipe with an oxyacetylene torch using a silver brazing filler metal containing cadmium. Seidal et al. (Ref. 230) described the case of a 78-year-old man who developed severe chemical pneumonitis and respiratory insufficiency 3 hours after having been in an enclosed room for 15 minutes where stainless steel was being brazed with a silver brazing rod containing 20-30% cadmium. An incident in which a man was hospitalized after oxyacetylene welding lead-coated iron plates was described by Ziegenfuss et al. (Ref. 287). A case of a smelter with hypersensitivity pneumonitis, apparently induced by exposure to zinc oxide fumes, was described by Ameille et al. (Ref. 5). His symptoms were similar to metal fume fever, but they took 3 to 7 days to resolve.

Glass et al. (Ref. 91) described a 32-year-old welder who developed chronic interstitial lung disease after several years of welding galvanized steel using GMAW in a poorly ventilated shop. The physicians related his dis-

case solely to his welding experience, but it is also possible that his experience between the ages of 28 and 32 repairing and spray painting fiberglass boats may have contributed to his condition. The case of a shipyard welder who died of mesothelioma was described by Levin (Ref. 159). His condition had been largely attributed to his welding experience in a shipyard, but he had also worked as a laundromat operator for 15 years where part of his duties involved frequent disassembly and sanding of washing machine clutch linings which contained 10 to 12% chrysotile asbestos. Figueroa et al. (Ref. 72) described two cases of hard metal pulmonary interstitial fibrosis in men employed at a plant where hard metal coatings were applied to premanufactured metal parts using the detonation gun process.

## Cancer

**Lung Cancer.** A commission of the International Institute of Welding concluded that there is sufficient evidence that welders as a group have a slightly greater risk of developing lung cancer than the general population (Ref. 290). They noted that the extent to which asbestos exposure and smoking contribute to the increased incidence of lung cancer among welders is unknown. Several studies (Refs. 58, 134, 136, and 183) published between 1992 and 1994 addressed the contribution of asbestos and smoking to lung cancer among welders, and some studies attempted to distinguish between the risk of cancer associated with stainless steel and mild steel welding. Moulin et al. (Ref. 183) extended the French portion of the previously published nine-nation historical cohort study sponsored by the International Agency for Research on Cancer (Ref. 234) and found that lung cancer deaths were significantly increased among those who had been welding mild steel for at least 20 years or who had had their first welding experience at least 20 years prior to the start of the study. Danielson et al. (Ref. 58) found that the lung cancer incidence among welders in a Norwegian shipyard was significantly higher than that in the Norwegian male population. Pleural mesotheliomas occurred in four non-welders in the shipyard population, suggesting that all the shipyard workers, including welders, had been exposed to asbestos. The authors concluded that there was an excess lung cancer risk among the mild steel welders in the shipyard, even after accounting for exposure to asbestos and smoking.

Merlo (Ref. 176) found that workers employed in an Italian shipyard between 1960 and 1988 had significantly elevated mortality for all cancers and specifically for lung cancer and mesothelioma. Welders were not studied separately from the shipyard workers. In a mortality

study of workers with two or more years employment at an automotive stamping plant, Park et al. (Ref. 202) found that lung cancer mortality was significantly elevated among production welders compared with assembly plant workers, and the risk for lung cancer increased with the duration of the welding experience. Welding was performed on sheet metal that was usually coated with drawing compound, and sometimes coated with primer or epoxy resin adhesive.

Jockel et al. (Ref. 134) examined interim results from a case-control study of lung cancer designed to control for smoking and asbestos use. There were significant elevations in the incidence of lung cancer among those highly exposed to asbestos and among aircraft industry welders. There was also an increased risk for lung cancer among welders as an occupation, but it was not significant after correction for smoking and asbestos exposure. Using the Illinois State Cancer Registry, Keller and Howe (Ref. 142) found a significant association between welding and lung cancer. A statistically significant excess of lung cancer deaths was also observed among male welders in a study conducted in New Zealand by Firth et al. (Ref. 73). Wu-Williams et al. (Ref. 283) found a statistically nonsignificant excess risk for lung cancer among female welders in Shenyang and Harbin, China.

Several investigators reanalyzed data from previously published studies to try to eliminate or control for the effects of smoking and asbestos. Sjogren combined data from five recent studies which appropriately controlled for smoking and asbestos exposure and found a significant relative risk for lung cancer among welders of stainless steel. Langard (Ref. 155) interpreted the data from the nine-nation historical cohort study sponsored by the International Agency for Research on Cancer (Ref. 234) as indicating that stainless steel workers are more likely to die of lung cancer than are welders as a whole. Marini (Ref. 166) disagreed with Langard's interpretation, pointing to the confounding influences of smoking and asbestos on lung cancer among welders. Langard (Ref. 157) also applied data from recent studies to estimate the number of lung cancer cases that could be attributed to various industrial exposures. He attributed about 150 of the 1100 annual cases among Norwegian males to asbestos exposure and fewer than two to welding of stainless steel. In another review of welders exposed to nickel and chromium, Langard (Ref. 156) concluded that welding of stainless steel poses a greater risk of lung cancer than welding of mild steel. Becker and Rittgen (Ref. 17) applied a mathematical model to a population of welders who had previously been found (Ref. 15) to have a significantly greater risk of death from lung cancer compared with machinists in the same plant. Their model failed to relate the duration of exposure to welding fumes to cancer mortality. Kromhout et al. (Ref. 153) demonstrated

that individual job histories were more successful in relating lung cancer morbidity to industrial exposures than were generalized job exposure matrices which used job titles to estimate exposures. Gerin et al. (Ref. 88) developed a matrix which estimated welders' exposures to nickel and chromium in various welding processes. The exposures to fume components estimated using this matrix could not be related to cancer mortality.

Verma et al. (Ref. 272) conducted an industrial hygiene survey to evaluate a Canadian study (Ref. 216) that had found an excess of lung cancer mortality among welders of lead in one nickel/copper smelter and refinery but not in another. The authors attributed the difference in lung cancer risk to polycyclic aromatic hydrocarbons, known carcinogens, which were found only in the plant with the excess lung cancer risk.

**Welding with Thoriated Electrodes.** Vinzents et al. (Ref. 273) calculated the radiation dose to the lungs of a welder using thoriated electrodes by measuring the dust generated in grinding the electrodes and calculating the vaporization rate of thorium from the estimated number of electrodes used during a lifetime of welding. The cancer risk, estimated using a standard lung model and internationally accepted risk factors for thorium isotopes, was less than three excess cancers in a group of 1200 lifetime welders. Crim and Bradley (Refs. 55 and 56) also measured air concentrations of thorium generated by grinding the tip of the electrode. Thorium activity in the respirable dust was consistently below the Nuclear Regulatory Commission standard. McElearney and Irvine (Ref. 170) examined thorium exposure in 75 welders and 61 controls employed by a British airline. Thorium was below detection limits in most of the urine samples collected from the subjects.

**Cancer in Organs Other Than the Lung.** Holt (Ref. 118) identified welding as an occupation possibly at risk for sino-nasal cancer. Zheng et al. (Ref. 285) studied the relationship between naso-pharyngeal cancer and industrial occupations, including welding, in Shanghai, China. The report was unclear about whether a relationship was found between this disease and welding. In a case-control study of sino-nasal cancer in France, Luce et al. (Ref. 162) found no association between exposure to welding fumes and any form of sino-nasal cancer.

Keller and Howe (Ref. 142) found a marginally negative correlation between welding and bladder cancer. In a case-control study conducted by Cordier et al. (Ref. 48), bladder cancer in males was related to welding, but this relationship lost its statistical significance when the data were adjusted for vital statistics and smoking. Zaridze (Ref. 284) also found a nonsignificant increase in the risk for bladder cancer among welders. Firth et al. (Ref. 1993) noted an increased incidence of stomach cancer among

welders, but did not discuss its statistical significance. Persson et al. (Ref. 206) found a marginally significant increase in the risk for non-Hodgkin's lymphoma, but not in the risk for Hodgkin's disease, among welders. Kauppinen et al. (Ref. 141) examined all cases of primary liver cancer reported to the Finnish cancer registry during a 4-year period and found that there was a significantly increased risk for this disease among welders exposed to fume concentrations of 2.5 mg/m<sup>3</sup> for ten or more years. In the shipyard population studied by Danielson et al. (Ref. 58), there was a marginally significant elevation in skin cancer which the authors attributed to UV radiation from the welding process.

**Electromagnetic Fields.** Theriault (Ref. 257) reviewed recent studies of EMFs and cancer and determined that the evidence is insufficient to conclude that EMFs cause cancer in humans. This conclusion was echoed in a review by McBride and Gallagher (Ref. 169). Two case-control studies failed to establish a link between welding-associated EMFs and leukemia. Ciccone et al. (Ref. 45) did not find an excess of leukemias among those exposed to welding fumes. Richardson et al. (Ref. 214) found a significantly increased risk for leukemia among EMF-exposed workers only when welders were removed from the group. Rosenbaum et al. (Ref. 222) did not find any association between male breast cancer and working in occupations, including welding, exposed to EMFs.

## Metal Fume Fever

Typical cases of metal fume fever in welders were described by Offermann and Finley (Ref. 192) and by Koh and Chia (Ref. 150).

Gordon et al. (Ref. 94) exposed four male volunteers for 2 hours via face mask to concentrations of ultrafine zinc oxide equivalent to the ACGIH Threshold Limit Value (TLV) of 5 mg/m<sup>3</sup> zinc oxide. Each subject developed one or more symptoms of metal fume fever within 6 to 10 hours after exposure. Blanc et al. (Refs. 21, 22) determined concentrations of the cytokines interleukin-1, interleukin-4, interleukin-6 (IL-6), interleukin-8 (IL-8), and tumor necrosis factor (TNF) in bronchioalveolar lavage fluid (BAL) fluid obtained from 23 welders at 3, 8, and 22 hours after exposure to fumes generated by welding galvanized mild steel. Concentrations of TNF, IL-6, and IL-8 varied with time after exposure and with the intensity of exposure. The investigators concluded that a network of cytokines, released from activated alveolar macrophages following the phagocytosis of metal oxide particles, is involved in the pathogenesis of metal fume fever.

## Effects on the Ear

Four cases of serious ear injuries inflicted by sparks produced by welding were reported (Refs. 40, 201, and 231). Panosian and Dutcher (Ref. 201) concluded that, although injuries to the ear are rare among welders, the risks warrant the use of ear protection while welding. They concluded that the ear protection guidelines of the American Welding Society (Ref. 7) should suffice to protect against the ear hazard that exists during welding procedures.

## Effects on the Eye

Three cases of maculopathy, attributed to inadequate, or improperly used eye protection while welding, were described by Fich et al. (Ref. 71). All cases (2 males and 1 female) were welding students. Lindblom (Ref. 160) described the case of a 52-year-old welder who experienced an acute loss of vision associated with pigmented scars in the fovea of both eyes.

## Effects on the Cardiovascular System

Using census data on the Danish working population and hospitalization records between 1981 and 1984, Tuchsén et al. (Ref. 263) evaluated the occupations with the greatest risk of heart disease in Denmark. No significant excess risk of heart disease was found for male welders but females in the occupational group defined as “unskilled welder, steel tube, and sheet construction worker” were found to have an excess risk of ischemic heart disease.

The potential association between vibration-induced white fingers (VWF) and changes in plasma viscosity and plasma components were investigated in 34 men, ten of whom were welders, by Toren et al. (Ref. 260). Plasma viscosity was significantly decreased in VWF patients who were current or exsmokers. No changes in plasma viscosity were seen in VWF patients who were nonsmokers.

## Effects on the Skin

**Thermal Burns.** Three cases of spot welders with severe, persistent dermal wounds on the hands were described by Giddins and Wilson-MacDonald (Ref. 90). The authors noted that the welders wore only cotton gloves to protect their hands and recommended that better protective materials be used. Almind and Broeng (Ref. 4) described a case of a welder who suffered a high-velocity, high-temperature injection injury to his

right index finger while conducting resistance welding without wearing protective gloves. Almind and Broeng stressed the need for rapid evaluation and treatment of this type of injury.

**Chronic Actinic Dermatitis.** Roelandts and Huys (Ref. 217) described the case of a 45-year-old welder who developed chronic actinic dermatitis, a condition of unusual sensitivity to UV radiation. After welding, he experienced a prickly sensation and then developed erythema and edema around the eyes, on the cheeks, chin, exposed area of the neck, and on the left arm.

**Scleroderma.** Scleroderma, an uncommon disease which causes the deposition of fibrous connective tissue in the skin, lungs, and other internal organs, is thought to be associated with occupational exposure to silica and/or hand-arm vibration resulting from use of vibrating equipment, such as pneumatic drills. Pelmear et al. (Ref. 203) described the case of a 44-year-old welder with scleroderma, who experienced hand-arm vibration from using a high-speed reamer, chipping hammer, impact wrench, and huck gun.

## Effects on the Nervous System

**Motor Neurone Disease.** In a case-control study, Gunnarsson et al. (Ref. 98) examined risk factors for motor neurone disease (MND), a fatal, progressive, neurodegenerative condition. The occupational histories and exposures of 92 MND cases were compared with 372 age-matched controls. Employment in electrical occupations and welding were associated with a significant risk for MND.

**Multiple Sclerosis.** In 1988, Flodin et al. (Ref. 75) reported finding that Swedish men who were exposed to both organic solvents and welding have an increased risk of multiple sclerosis. These investigators later conducted a similar study in a different geographical area of Sweden (Ref. 154). The second case-control study, which included 91 multiple sclerosis cases and 348 referents, did not corroborate their previous findings (Ref. 75) and showed no association between combined exposure to organic solvents and welding and the risk for multiple sclerosis. Gronning et al. (Ref. 95) also examined the relationship between multiple sclerosis and welding. These investigators conducted a case-control study which included 139 patients with multiple sclerosis and 161 controls who were hospital patients with unrelated diseases. No association was found between the risk for multiple sclerosis and occupational exposures to organic solvents, alone or in combination with welding.

**Aluminum Exposure.** Hanninen et al. (Ref. 100) evaluated the relationship between central nervous system function and urine and serum aluminum concentrations in 17 Finnish welders who had conducted GMAW of aluminum for 4 years. Correlations between neuropsychological test results and aluminum concentrations in serum and urine were inconsistent. The investigators concluded that the study suggested that aluminum uptake from welding exposures may have an effect on central nervous system function.

Using data from studies of dialysis patients with abnormal psychomotor function and from studies of aluminum retention in welders, Sjogren and Elinder (Ref. 235) estimated the maximum exposure level to aluminum fumes that could be used as a guideline to protect welders against impaired central nervous system function. They recommended that the time weighted average occupational exposure limits should not exceed 1 mg/m<sup>3</sup>.

## Effects on the Musculoskeletal System

Tregaskiss and Dutta (Ref. 261) found that ergonomic characteristics of welding guns, including weight, trigger activation force, and grip shape and diameter, were positively correlated with muscle forces measured in the shoulders and forearms of welders using gas metal arc welding guns. Strakova and Polach (Ref. 248) studied the forces necessary to open the clamp of the electrode holder while inserting a new electrode. Only one of the four clamps tested was found to be suitable for male welders with normal or larger hand size. Kadefors (Ref. 137) recommended workplace practices that could reduce the various causes of chronic musculoskeletal injuries in welders. Kadefors et al. (Ref. 138) described model workplaces which have been built in a Swedish research center that incorporate ergonomic designs to minimize strains and other features designed to improve the welder's work environment. Wanders et al. (Ref. 275) determined the incidence of locomotor disorders leading to termination of employment in a shipyard, and found that medical disability due to musculoskeletal disorders was same for welders as for other workers.

## Effects on the Kidney

**Cadmium.** Holmquist et al. (Ref. 117) examined the utility of urinary levels of the protein apolipoprotein D (apo-D) as a marker for kidney tubular damage. While apo-D became elevated in the urine of cadmium-exposed workers, it proved to be a less-sensitive indicator of exposure than the routinely used marker alpha1-microglobulin. However, the investigators concluded that, be-

cause it is more stable than other proteins used to diagnose this condition, apo-D may be a useful complement to alpha1-microglobulin levels for diagnosing kidney tubular malfunction.

**Chromium.** Vyskocil et al. (Ref. 274) studied the effect of chronic exposure to low levels of chromium on kidney function in 52 male stainless steel welders with an average of 18 years exposure to chromium-containing fumes. The mean breathing zone concentration of water-soluble Cr(VI) compounds was slightly higher than the TLV and that for nickel was about half the TLV. The urinary excretion of total proteins, albumin, protein-1, transferrin, retinol-binding protein, lactic dehydrogenase, beta2-microglobulin, lysozyme, and beta-N-acetylglucosaminidase did not differ significantly between welders and controls. The investigators concluded that if Cr(VI) compounds can produce renal changes in exposed persons, such effects are unlikely to occur in workers exposed to airborne concentrations at or below the TLV.

## Fertility

Baranski (Ref. 12) reviewed the literature on the effects of occupational factors on fertility and reproduction. He noted that designing human fertility studies is difficult because of the normally high rate of infertility in the general population. Seven of the studies considered by Baranski examined the effect of welding on the male reproductive system. Of these, he found three to be adequate in terms of study design.

Bonde and Ernst (Ref. 32) examined semen quality in 30 welders who performed GTAW of stainless steel, 30 welders who performed SMAW or GMAW of mild steel, and 47 controls. There was no correlation between chromium levels in blood or urine and deterioration of any of the semen parameters tested or concentrations of follicle stimulating hormone (FSH) and luteinizing hormone (LH) in blood. The investigators concluded that the low-level exposure to hexavalent chromium encountered by the majority of the welders in this study had no effect on the male reproductive system.

Bonde (Ref. 29) studied 17 welders with long-term moderate exposure to radiant heat who were highly protected from fume exposure by local exhaust ventilation and compressed air respirators. A significant difference in the proportion of sperm with normal shape was observed at the end of a 4-week vacation period compared with that in semen collected 8 to 32 weeks after resuming work. It was concluded that welders in this study experienced a reversible decrease in semen quality, most likely caused by a moderate exposure to radiant heat.

In a third study, Bonde et al. (Ref. 34) investigated whether paternal welding exposures affect the outcome of pregnancy or cause an excess in childhood malignancies or birth defects. Data were collected from 8376 metal workers who had fathered 3569 children between 1973 and 1986. The only detrimental result related to welding that was seen in the study was an association between paternal stainless steel welding, but not mild steel welding, and the occurrence of spontaneous abortion. The Odds Ratio was greater for pregnancies at risk from SMAW than from GTAW, which supported an exposure-response relationship. The data on spontaneous abortions were re-examined and, in 1995, Bonde and associates (Ref. 13) published a report retracting their earlier findings (Ref. 34). The new data showed that there was no increase in the occurrence of spontaneous abortions among wives of welders.

Working with data published by Bonde et al. (Ref. 34), James (Ref. 129) calculated that records of more than 40 000 births would be necessary to begin to detect statistically meaningful abnormalities in the sex ratios of children born to welders. Schnitzer et al. (Ref. 229) conducted a population-based case-control study which examined if there are associations between birth defects and several paternal occupations. Welders were found to have offspring with a nonsignificantly elevated incidence of hydrocephalus. Moskova and Popov (Ref. 181) reported that the incidence of deviations in sperm motility and morphology was significantly higher among 30 Bulgarian welders than among controls.

## Effects of Manganese

In her report of OSHA compliance inspections at two welding facilities, Franek (Ref. 76) described a case of manganese poisoning in a welder who had worked on railroad tracks since 1983 without using respiratory protection. In 1991, he developed "classic signs and symptoms of long-term manganese exposure."

## Effects of Mercury

An incident in which 53 workers were exposed to high levels of mercury for up to 16 hours while performing maintenance work on a mercury cell at a chlorine manufacturing plant in East Tennessee was described by Bluhm et al. (Ref. 24). A number of the men became ill after the incident and were referred to Vanderbilt University Hospital. Eleven of the patients with the highest mercury levels were followed for 18 months. The half-lives of mercury in blood and urine were estimated to be 45 and 56 days, respectively. Decrements in performance

in neuropsychological tests of visual-motor skills continued throughout the 18-month follow-up period.

Barregard et al. (Ref. 13) determined the rates of elimination of mercury from urine and blood following intense short-term occupational exposure to mercury vapor in nine men, including two welders, involved in dismantling and assembling mercury-contaminated equipment in a chloralkali plant. The median half-time of urinary mercury was 40 days. Based on the relationship between environmental mercury concentrations and urinary and blood mercury levels, the investigators did not advise the use of biological monitoring for intermittent mercury exposures.

## Effects of Lead

**Bone Lead Measurements.** Because long-term storage occurs in the bone, lead levels in bone can serve as an indicator of cumulative lead exposure. Using X-ray fluorescence, Gamblin (Ref. 78) determined baseline lead levels in the tibia in a nonoccupationally exposed population of 111 subjects from Southern Ontario. They found that bone lead increased steadily with age. Bone lead was measured in an additional 27 subjects with potential occupational exposures to lead fumes and dusts. Seven of these workers, including two of the six welders who participated in the study, had tibia lead levels greater than the upper limit of the normal range established with the nonoccupationally exposed subjects. Only two of the 27 occupationally exposed workers had lower than normal levels. Watanabe (Ref. 227) tested blood and bone lead levels in 127 volunteers from the International Brotherhood of Carpenters and Joiners. Blood lead levels were low, with a mean of 8.2 µg/dL. Age-adjusted tibia lead was positively associated ( $p < 0.10$ ) with paint stripping, demolition, plumbing, and welding/brazing.

**Metallothionein.** A metallothionein-like protein that binds lead was isolated from erythrocytes and characterized by Church et al. (Ref. 44). High concentrations of this protein were found in erythrocytes collected from a welder who had extremely high blood lead levels (1800 µg/L) but showed no symptoms of lead poisoning. In contrast, a patient with severe symptoms of lead poisoning had low concentrations of this protein compared with the welder. These findings suggested that this lead-binding metallothionein protects cells against heavy metal toxicity by sequestering circulating lead and reducing its bioavailability within the body.

**Treatment of Lead Poisoning.** Chelation with calcium disodium ethylenediaminetetraacetate (EDTA) is generally considered to be the method of choice for treatment of lead poisoning. In a study conducted with welders

who had been hospitalized with lead poisoning, De Paris and Caroldi (Ref. 61) showed that EDTA causes sufficient copper to be withdrawn from the blood to cause a 95% inhibition of the copper-dependent enzyme, serum dopamine-beta-hydroxylase. The enzyme level returned to normal within 24 hours after treatment with EDTA.

Linz et al. (Ref. 161) described a case in which chelation with EDTA caused improvement in neuropsychologic function in a bridge worker with mild lead poisoning. The patient developed symptoms of lead poisoning while arc welding and oxyacetylene cutting galvanized steel during a bridge dismantling project.

**Paget's Disease.** Paget's disease is a chronic condition in which bone resorption is increased, followed by an increase in disorganized bone formation. Detailed occupational histories demonstrated that lead exposure was a common feature among 32 patients with this disease, five of whom were classified as solderers, welders or plumbers.

## Antioxidants

Mongiati et al. (Ref. 178) found that the concentration of ceruloplasmin, a serum protein with antioxidant activity, was significantly elevated in smoking welders compared with nonsmoking welders and smoking and nonsmoking controls. They conjectured that increases in serum ceruloplasmin levels may represent an adaptive mechanism against the oxidants in welding fumes and cigarette smoke.

## Biological Monitoring

**Barium.** Zschiesche et al. (Ref. 292) measured the breathing zone concentrations and the concentration of barium in plasma and in spot urine samples from welders using barium-containing flux cored or covered electrodes under controlled conditions for a period of 1 week. Based on urinary excretion rates during the weekend following the study, the biological half-life of barium in urine and plasma was calculated to be between 10 and 18 hours. Clinical examinations administered to welders throughout the study period indicated a transient, non-dose-related decrease in plasma potassium levels.

Zschiesche and Schaller (Ref. 291) noted that there are large inter- and intra-individual variations between external barium exposures and barium concentrations in plasma and urine. Because of this, and the wide overlap in the barium concentrations in plasma and urine between persons with low occupational barium exposures and those with no occupational barium exposures, they suggested that the barium content of biological fluids

may best be used to demonstrate any changes which occur in barium exposure over a course of time or to monitor group exposures to barium.

**Cadmium.** Trevisan et al. (Ref. 262) and Perret et al. (Ref. 204) showed that spot urine samples are suitable for biological monitoring of cadmium exposure when they are adjusted for urinary creatinine concentrations. Adjustment for specific gravity appeared to be of no benefit. Perret recommended that urine samples for biological monitoring of cadmium exposure be routinely collected in the evening, when cadmium excretion is least variable.

**Chromium.** The relationship between environmental workplace exposures and concentrations of nickel and chromium in blood, serum, and urine from 40 shielded metal arc welders of stainless steel was studied by Stridsklev et al. (Ref. 249). The total chromium concentration in blood and plasma generally increased during the workday but not over the workweek. The concentrations of total chromium and Cr(VI) in the workplace air were significantly correlated with the total chromium in the blood and urine. Nickel concentrations in the blood and urine did not correlate with air concentrations. These results indicated that urine samples collected after the work shift are useful for routine monitoring of chromium, but not nickel, in stainless steel welders. Chromium and nickel levels were also measured in urine and blood collected for one workweek from 14 welders performing GTAW of stainless steel (Ref. 250). Based on the findings that nickel and chromium concentrations were not elevated in blood and urine from eleven welders who had no bystander-exposures to other processes, Stridsklev et al. concluded that biological monitoring is not appropriate for gas tungsten arc welders of stainless steel.

**Cobalt.** The relationship between environmental cobalt exposures and urinary cobalt concentrations was examined by Ferri et al. (Ref. 70) in five oxyacetylene braze welders and three gas metal arc welders of stellite. A cumulative increase in urinary cobalt levels through the workweek was found in gas metal arc welders, which suggested that cobalt may accumulate in workers with continuous exposures to cobalt. A mean urinary concentration of 31 µg/L was found to be equivalent to the cobalt TLV of 50 µg/m<sup>3</sup>.

**Lead.** A survey of blood lead concentrations in 264 construction workers was conducted in the state of Maryland by Sokas et al. (Refs. 240 and 241). The mean blood lead concentration of the entire cohort was 8 µg/dL; the geometric mean for the U.S. population is 2.8 µg/dL.

**Manganese.** To correlate manganese levels in blood and urine with occupational exposures, Jarvisalo et al. (Ref.

130) conducted studies with 15 male shipyard welders who performed SMAW of mild steel. A poor correlation was found between breathing zone measurements of manganese and the levels of manganese in blood and urine. The investigators concluded that the measurement of manganese in urine or blood may be used for monitoring manganese exposure in gas metal arc welders only at the group level.

**Plutonium.** The case of a 44-year-old male welder whose exposure to the alpha-emitter plutonium-239 (Pu-239) was detected by routine monitoring of urine at a nuclear reactor fuel reprocessing facility was described by Hedge et al. (Ref. 107). The clearance of Pu-239 from the welder's body was monitored by measuring radioactivity levels in urine and feces. The authors concluded that fecal excretion data can be used to estimate initial Pu-239 lung burdens following inhalation exposure.

## Biomarkers

**Genotoxicity.** Knudsen et al. (Ref. 149) investigated the frequency of sister chromatid exchange (SCE), chromosomal aberrations, and unscheduled DNA synthesis (UDS) in lymphocytes obtained from 127 Danish stainless steel welders. The frequency of chromosomal aberrations was higher and that of SCE was lower in stainless steel welders than in non-welders. Significant differences in the frequencies of UDS and SCE were seen only when nonsmoking welders were compared with nonsmoking controls. Among non-smokers, the frequencies of both UDS and SCE were lower in welders than controls. Jelmert et al. (Ref. 131) found no increase in the number of SCE in either smoking or nonsmoking stainless steel welders compared with controls with the same smoking habits. A small increase in chromatid breaks and in the number of cells with chromosomal aberrations was noted in lymphocytes from the stainless steel welders but a positive correlation between chromosome aberrations and welding only showed up after they had welded stainless steel for at least 1 year. Costa et al. (Refs. 50–52 and 259) found a significant increase in DNA-protein cross-links in peripheral white blood cells collected from 21 shielded metal arc welders who frequently used high manganese-nickel-chrome electrodes.

Frenkel et al. (Ref. 77) tested whether the presence of antibodies to oxidized DNA bases in the blood stream can serve as biomarkers of exposure to inflammatory metal particles. A positive correlation was found between cadmium and nickel exposures and the titers of antibodies to an oxidized DNA base in blood cells from 31 workers exposed to cadmium and nickel at a Polish bat-

tery factory. However, there was only a nonsignificant increase in the concentration of antibodies to oxidized DNA in blood from 27 American railroad track welders who were exposed to welding fumes containing manganese, nickel and chromium.

**Hair and Nails.** Gorban et al. (Ref. 93) measured the manganese (Mn) content of hair from 228 welders who welded steel using electrodes with a high Mn content. The Mn content of hair samples collected from welders correlated positively with breathing zone welding fume concentrations. When welders who stopped welding after the first tests were conducted were retested 7 years later, the Mn content of their hair was indistinguishable from that of the controls.

Nagra et al. (Ref. 187) compared the concentrations of 15 trace elements in hair and fingernail samples obtained from 50 industrial workers living in Hamilton and Toronto, Canada. Hair samples from the workers contained markedly higher levels of Cd, Fe, Mn, and Mo compared with values reported for the general population of the U.S.A., while the levels of all elements were higher in nail samples obtained from workers compared with the general Canadian population.

## *Investigations in Animals and Cell Cultures*

### Fertility

Ernst and Bonde (Ref. 67) exposed rats 5 days/week for 8 weeks to Na<sub>2</sub>CrO<sub>4</sub> [Cr(VI)]. In rats examined immediately after the 8-week exposure period, there was a significant reduction in the number of motile sperm and serum testosterone levels. Concentrations of LH and FSH were significantly increased in serum. All of the sperm parameters and most of the hormone levels were normal at the end of an 8-week treatment-free recovery period, indicating that the effects of Cr(VI) on the male rat reproductive system are reversible.

### Effects of Electromagnetic Fields on Fetal Development

Kowalczyk et al. (Ref. 152) exposed pregnant mice to levels of electromagnetic radiation that could be experienced by arc welders. Exposure to EMFs had no effect on survival rates of fetuses and did not cause external, internal, or skeletal abnormalities.

## Metal Fume Fever

Gordon et al. found that exposure to 5 mg/m<sup>3</sup> ultrafine zinc oxide particles for up to 3 hours caused acute inflammatory changes in the lungs of guinea pigs and rats, but not rabbits (Ref. 94). Indicators of acute inflammatory changes in the lung were elevated in BAL fluid from guinea pigs and rats but not rabbits. The differences in response among the three species were attributed to the fraction of the inhaled zinc oxide that was retained in the lungs.

## Antioxidants

Geleskul et al. (Ref. 85) showed that intratracheal instillation of welding fumes can result in peroxidation of lipids in the lungs and liver. Treatment with antioxidant vitamins (vitamins A, C, and E) before or after administration of welding fumes markedly inhibited the oxidation of lipids (Refs. 79 and 80).

## In Vitro Studies

Feren et al. (Ref. 69) showed that welding fume particles were more cytotoxic to cultured epithelial cells than were nickel subsulfide particles. They attributed the differences to the soluble chromates released from welding

fumes. Otmane et al. (Ref. 194) found that fume particulates generated by SMAW of stainless steel were more cytotoxic to guinea pig alveolar macrophages than were fumes from GMAW of stainless steel or GMAW of cast iron using a pure nickel welding electrode. These differences were attributed to the soluble hexavalent chromium component of the fumes.

## Gene Expression

Three investigations determined quantities of specific mRNAs as a measure of the induction of the synthesis of specific proteins in the lung by emissions from welding processes. In the first study, conducted by Wiethege (Ref. 282), rat alveolar macrophages were incubated *in vitro* with quartz dust, welding fumes, and crocidolite asbestos. Macrophages stimulated by quartz dust showed the highest rate of expression of TNF mRNA, followed by welding dust, then crocidolite. A similar study by Ossege et al. (Ref. 193) showed that crocidolite, quartz and welding fumes can induce the synthesis of alpha-2-macroglobulin by isolated rat alveolar macrophages. In the third study, Cosma et al. (Ref. 49) exposed rats by inhalation for 3 hours to zinc oxide particles and for 6 hours to ppm ozone. Zinc oxide fume caused substantial increases in the mRNAs specific for metallothionein and heme oxygenase. In contrast, ozone caused no increase in the mRNA for either enzyme.