Effects of Welding on Health, X

American Welding Society

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

Effects of Welding on Health, X

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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.

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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:

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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.

EWH—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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Truck Trailer Manufacturing Association
Walker Stainless Equipment Company
Weld Tooling Corporation

Many other organizations have also made contributions to support the ongoing program from May 1979 to the present.

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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_1 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_1 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_1 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_1 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^3 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, Beaufils (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-pyridylhydrazone 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 $\mu g/m^3$ 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 mg/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 substantially 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_2 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 μT, peak exposures exceeded 10 μT, and exposures greater than 5 μT 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^3 for spot welding in automatic lines and from 0.16 to 0.80 mg/m^3 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 preemployment 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_1 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_1 and FEV_1/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_1 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_1 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. Shmuter (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-

ease 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^3 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^3 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, Tuchsen 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^3.

Effects on the Musculoskelatal 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, because 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, lysozome, 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 dismounting 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

Mongiat 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 $\mu g/m^3$.

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 battery 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_2CrO_4 [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

Kowalczuk 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^3 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.

Effects of Welding on Health, X

Section One
The Exposure

1. Fume Composition

In metal arc welding, the rate of fume generation and the composition of the fume are influenced by many factors including arc voltage and welding current, the composition and flow rate of shielding gases in gas metal arc welding (GMAW), the composition of the flux in shielded metal arc welding (SMAW), the composition of alloying materials or slag formers in flux cored arc welding (FCAW), the composition of the electrode or filler metal, the metal transfer mode and, to a limited degree, the base metal.

In GMAW, the welding rod is the source of 70 to 90% of the welding fume; the remainder comes from spattered particles and the molten welding pool. Except when coated with volatile materials, the workpiece contributes only about 10% of the metal fume. The fume generation rate (FGR) rises with increasing voltage up to about 30 volts (V) then decreases as spray transfer becomes dominant and spatter is minimized. As the voltage increases above about 40 V, the FGR once again increases with increasing voltage (Refs. 133 and 110).

The composition of the fume depends upon the mechanism by which it is produced. Evaporation of the more volatile components (fractional evaporation) may occur at the weld; some unfractionated evaporation occurs from hot droplets or spatter. Results presented by Hewitt (Ref. 110) of experimental welds using GMAW with five different welding wires on a stainless steel workpiece showed that the relative concentration of iron in the fume is slightly less than that in the alloy being welded, chromium is slightly higher in the fume than in the alloy, and, because of its much greater volatility, manganese is represented in the fume at eight times its proportion in the alloy. Calculations based solely upon relative boiling points predicted even higher Mn concentrations than were found in the fume.

The shielding gases in GMAW also affect the FGR. Increasing the oxygen in the shield gas from zero to 8% doubled the FGR. Shielding the weld from atmospheric oxygen is also important. Experimentally increasing the oxygen content of the weld environment from zero to 20% more than doubled the FGR. Adding 5% CO_2 to an argon shielding gas halved the FGR. The FGR increased as the concentration of CO_2 in the shielding gas was raised above 5%, possibly because it became a source of oxygen. Hewitt (Ref. 110) also noted that other gases, such as ozone (O_3) and the oxides of nitrogen (NO_x), play a part in fume composition and FGR.

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 shielding gas was 80% Ar and 20% CO_2. Most of the particles were below 1 μm in diameter. In the spray transfer mode, the size distribution of the particles was independent of the arc voltage or the welding current. The FGR increased with the welding current, arc voltage, and deposition rate. In this study, FGR was best correlated with arc power (current times voltage).

Hewitt and Hirst (Ref. 109) examined the effects of modifying the flux constituents of flux cored electrodes on the concentrations of metal components in the fumes. They used a fume box similar to that recommended by the American Welding Society (Ref. 6) to measure FGR and to collect fumes generated by FCAW using specially prepared welding electrodes containing from zero to 10% rutile (titanium) or basic slag formers in the cores. Welding was performed at a constant 23 V and under identical conditions with each type of welding electrode. The FGR was unaffected by the content of either rutile or basic slag formers. The iron, chromium, and nickel content of the fume decreased as the rutile content of the electrode increased. Manganese, however, did not follow the same pattern. The Mn content of the fume was at a minimum when the electrode contained 2% rutile and increased when the electrode contained greater than 2% rutile or contained no slag formers. Increasing the slag content of the basic-cored electrodes resulted in a

decrease in all the metals, including Mn, in the welding fumes.

The authors pointed out that, with FCAW, the slag coating may act as a physical barrier to evaporation of molten metal in the weld and may also inhibit fume formation by reducing turbulence in the weld pool, inhibiting physical processes such as bubble bursting, and restricting spatter production. In addition, some oxidation products may be retained in the slag rather than being released in the fume. Toxic components of the flux core, such as Mn and sometimes Cr, oxidize and may then vaporize as fume. They recommended the use of flux cored wires to reduce fume formation and the use of safer substitutes for hazardous materials in the core. They noted that the formation of hexavalent chromium [Cr(VI)] can be reduced by removal of sodium from the flux.

Beaufils (Ref. 14) examined the emissions produced by braze welding steel to brass in a laboratory setting in which the welding conditions could be controlled and the concentrations of the components of the fumes could be measured. Boron, copper, iron, and zinc were measured in the fumes generated by braze welding various brass compositions to mild steel and galvanized mild steel. The emission of all of the metallic pollutants, especially zinc, increased with the welding temperature. For example, welding a brass composition to galvanized steel at 830°–860°C produced 3.9 mg zinc per second while at 970°–1010°C, it produced 26.2 mg zinc per second.

Using the Swedish fume box technique, Boekholt (Ref. 25) examined the composition of fumes emitted from The Lincoln Electric Company Innershield electrodes and compared them with fumes generated by welding with covered electrodes. Some Innershield electrodes produced more emissions than comparable covered electrodes.

2. Analytical Methods

In his review of methods for sampling and analysis of welding fume, Sarma (Ref. 226) recommended polyvinyl chloride membrane filters as the most suitable for collecting welding fume samples, X-ray fluorescence for metals analysis, chemiluminescence monitors for O_3 and NO_x, and nondispersive infrared (IR) instruments for carbon monoxide. 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 GMAW of mild steel. The analytical method was tested with standard reference samples and shown to be accurate. 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. Concentrations of Cr were 15.6 mg/m^3 using the glass filter and 3.9 mg/m^3 using the cellulose filter. Lanthanum, which is sometimes present in the flux on welding rods, was measured at 19.8 mg/m^3 using a glass fiber filter and at 0.005 mg/m^3 using a cellulose filter. The authors observed that hot particles may burn through a cellulose filter, but not through the heat-resistant glass fiber filter which is the probable reason for the observed differences.

2.1 Chromium. Chromium can be present in welding fumes in three oxidative states: elemental chromium [Cr(0)], trivalent [Cr(III)], or Cr(VI). The toxicologic properties of these three species differ and, because of its potential to induce cancer, Cr(VI) is the chromium species of greatest concern. Cr(VI) is labile and readily reduced to Cr(III) by reducing agents and by acidic conditions. Methods for collection, storage and analysis of air samples have been the subject of much discussion and experimentation over the past three decades.

Andrews and Hanlon (Ref. 8) reported that the reduction of Cr(VI) can be minimized by collecting samples on inert filters, storing samples under desiccation, and analyzing samples as soon as possible after collection. Several investigative groups have shown that Cr(VI) can be reduced to Cr(III) when fumes are stored on cellulose acetate or cellulose nitrate filters but not on glass fiber or PVC filters. While fumes are normally collected on glass or PVC filters, some investigators have collected fumes by impingement in water or alkaline solutions, on the theory that impingement provides a more complete recovery of Cr(VI) (Ref. 59).

Blakely and Zatka (Ref. 20) extracted chromates from fumes with sodium carbonate at high pH to avoid the reduction of Cr(VI) which can occur under the acidic conditions originally described in the method recommended by the National Institute for Occupational Safety and Health (NIOSH). In a related method, Cr(VI) is extracted from filters containing welding fumes with Na_2CO_3 and NaOH (Gray EWH 4 ref 51). Perchlorates have been used to solubilize Cr from the solid residue after Cr(VI) has been extracted (Ref. 8).

In 1994, Spini (Ref. 243) described a method for analysis of chromium in welding fumes based on selective solubilization of Cr(0), Cr(III) and Cr(VI). PVC or glass fiber filters on which the fumes have been collected are refluxed in a solution of 3% Na_2CO_3 and 2% NaOH to extract Cr(VI) and soluble Cr(III). Insoluble Cr(III) and Cr(0) are then selectively solubilized using an alkaline

peroxide solution followed by extraction with a 5:1 mixture of concentrated perchloric and nitric acids. Cr(VI) is determined spectrophotometrically using S-diphenyl carbazide, and Cr(III) and Cr(0) are determined by atomic absorption spectroscopy (AAS).

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. Three Greenberg-Smith impingers were operated in series at 15 LPM for 24 hours. The impingers were filled with 200 mL sodium bicarbonate solution (pH 8). He found that samples can be stored in the collection medium for up to 100 days without appreciable loss of Cr(VI).

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. Samples were prepared with a Sputnic air-sampling unit which is designed to collect fumes at the same rate from the same point source simultaneously on up to 100 filters. In preliminary studies, welding fumes were collected on 100 filters, with the air inlet of the Sputnic unit placed 1.3 m from a welder engaged in GMAW of mild steel. Four metals in the fumes (Fe, Mn, Cu, and Ti) were analyzed and found to be evenly distributed on the filters (Ref. 9). For the preparation of reference materials, welding fumes generated by a computerized SMAW process were collected simultaneously on 100 binder-free borosilicate glass fiber filters. This procedure produced filters that contained a mean of 2.565 mg fume per filter (the relative coefficient of variation or RCV = 3.4%), an average Cr(VI) concentration of 115.9 µg/filter (RCV = 1.9%), and an average total chromium concentration of 112.8 µg/filter (RCV = 4.4%). Trivalent chromium was not detected. Stability studies showed that the Cr(VI) content of loaded filters was stable when dry, loaded filters were stored at either 25°C or –20°C for up to 13 weeks. The authors concluded that this technique can produce homogeneously distributed stable Cr(VI) samples for use as reference materials.

2.2 Fluoride. Vasconcelos et al. (Ref. 271) developed a solid-phase extraction/ion chromatography procedure for determining fluoride in welding fumes. The method was designed for use with fume samples collected on cellulose nitrate filters by personal air samplers. Soluble salts were extracted from the filters by ultrasonication in water or a sodium bicarbonate/carbonate solution. A precolumn containing a cation exchange resin was used to eliminate interferences from trivalent iron and aluminum. Thirteen welding fume samples containing 0.6 to 18 mg/L fluoride were analyzed by ion chromatography and the data were compared with results obtained by a well established ion selective electrode procedure. Results obtained by the two methods were in good agreement. The authors concluded that ion chromatography is preferable to the ion selective electrode procedure when a more rapid and sensitive technique is required.

2.3 Nickel. Nickel concentrations are routinely measured in welding fumes by flame 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-pyridylhydrazone followed by extraction with methyl isobutyl ketone. This method was applied to metal fume samples collected on cellulose-ester membranes in a workplace environment.

2.4 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. The detection limits for chromium in blood and serum were 0.20 and 0.17 µg/L, respectively. The method was used to determine chromium levels in 23 blood and 77 serum samples from subjects who had served as referents in Danish welding surveys (Ref. 31). The mean blood and serum chromium concentrations were 0.18 and 0.25 µg/L. In 13 blood and 35 serum samples, chromium concentrations were below the detection limits. The reference values of blood and serum chromium ranged from 0.12 to 0.34, and 0.04 to 0.35 µg/L, respectively. These values are within ranges reported by other investigators.

Delta-aminolevulinic acid (ALA) is a biochemical intermediate formed during the synthesis of heme (the nonprotein component of hemoglobin). ALA can accumulate during episodes of lead poisoning, and urinary excretion of ALA is frequently used as a biological marker of adverse health effects resulting from lead exposure. The standard method for determining ALA in urine is too insensitive to measure ALA at the levels found in human serum or plasma samples. Tomokuni et al. (Ref. 258) explored the possibility of using a fluorometric high pressure liquid chromatography (HPLC) method for this purpose. ALA was determined in serum and urine samples from 16 workers from a lead smelter factory whose blood lead levels ranged from 19 to 107 µg/dL. Using the HPLC procedure, a strong correlation was found between the concentrations of ALA in serum and in urine. The concentrations of ALA in urine and serum also correlated well with blood lead concentrations. The investigators suggested that the measurement of serum ALA, as

well as urinary ALA, may be useful for the biological monitoring of occupational lead exposure.

Pan and Huang (Ref. 198) developed a method using mercury/hydride AAS and cold vapor AAS to measure concentrations of arsenic and mercury in urine. The method was tested with urine collected from 28 workers, including seven welders, in a metal pressing factory in Taiwan, China.

2.5 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) quantified bypass leakage in two different filter cassettes in a laboratory environment and conducted a field study for the quantification of bypass leakage in a welding shop. A significant difference existed between the two filter cassettes. Procedures for testing internal leakage were established in order to minimize the risk of underestimating workers' exposure.

3. Workplace Exposures

Harris and Carter (Ref. 104) investigated the cause of excessive lead concentrations encountered by welders who were fitted with personal monitors while air carbon arc cutting (CAC-A or air-arc gouging) using copper-clad carbon electrodes inside vessels at an oil refinery. All but one of 17 breathing zone samples collected during the arc gouging contained lead above the detection limit of 1 µg per sample. Nine samples were above the Occupational Safety and Health Administration (OSHA) action limit of 30 µg/m^3, and seven of these were above the OSHA time-weighted average (TWA) permissible exposure limit (PEL) of 50 µg/m^3. Lead was not detectable in air samples collected during SMAW in the absence of arc gouging operations. After the investigators reviewed potential sources of lead and eliminated other possibilities, the copper-clad carbon electrodes were examined. Lead was not detected when samples of the copper cladding or the carbon electrode were analyzed by atomic absorption analysis or by scanning electron microscopy. A bench test was set up in which twelve electrodes were consumed in a fume collection chamber (Ref. 6). Lead was found in fume samples generated by each electrode, but the concentrations were highly variable and ranged from 79 to 589 µg per electrode. The ratio of lead to copper was also highly variable, ranging from 0.28% to 1.43%. The authors concluded that the lead was present as small masses or irregular concentrations that were missed when random samples were taken from the electrodes. They also noted that since lead comprised less than 1% of the total mass of the electrode, its disclosure would not have been required on the Material Safety Data Sheet. Furthermore, the lead would not have been identified had they not performed a broad spectrum analysis, in which the number of analytes tested exceeded regulatory requirements.

Karlsen et al. (Ref. 139) determined the composition of fumes and dusts produced by SMAW and GMAW of stainless steel and grinding of the weld. Fumes were collected in the welders' breathing zone under controlled or "semilaboratory" conditions and in welding shops where normal operating conditions prevailed. In the controlled experiment, specimens were collected during 2 days of SMAW of stainless steel when no grinding was performed, and during one day of grinding on the welded area of the workpiece when no welding was being performed. In the welding shop experiment, specimens were collected at two shipyards for 5 consecutive days. Welding was performed on a nickel-rich material using SMAW and GMAW.

Analysis of fumes and dusts collected under controlled conditions showed that the contents of Mn and total Cr were lower in grinding dust than in welding fumes. The grinding dust contained proportionately more iron. Hexavalent chromium, which was present in concentrations of 300 µg/m^3 in welding fumes, was undetectable in grinding dust. Samples collected in the welding shops, where grinding and welding were concurrent, contained about 30% less Cr(VI) than did fume samples collected under controlled conditions in the absence of grinding. In the welding shop experiments, Ni, Fe, and Mn were higher in fumes collected during GMAW than during SMAW, but GMAW generated lower breathing zone concentrations of Cr(VI). Hexavalent chromium concentrations were 1.2 µg/mg in GMAW fumes and 14 µg/mg in SMAW fumes.

As part of a joint Norwegian-German study sponsored by the World Health Organization, Karlsen et al. (Ref. 140) determined the concentrations of total dust, Ni, Cr, Cr(VI), and Mn in workshop area air samples and in breathing zone air samples collected during SMAW of stainless steel under different workplace conditions. This work provided the background exposure data used to support three other studies discussed in this volume of the *Effects of Welding and Health.* The first was a biological monitoring study of nickel and chromium in urine and blood (Ref. 249), the second monitored possible effects on chromosomes caused by welding fume exposures (Ref. 131), and the third was an epidemiologic cancer study (Ref. 58). Samples were taken in three types of work sites: inside a ship section where the ventilation was poor; inside an offshore well module where air exchange was provided by passive ventilation; and in workshops where benchwork was usually performed with general and local ventilation. The lowest fume con-

centrations were found in the well module and the highest were found in the ship section, where mean and median fume concentrations in breathing zone samples were 5.4 and 2.7 mg/m^3. Corresponding measurements were 230 and 130 μg/m^3 for total chromium, and 140 and 48 μg/m^3 for Cr(VI). In one of the workshops, where the surfaces of stainless steel sinks were ground and polished in the absence of local ventilation, mean and median concentrations of Cr in the breathing zone were 1100 and 920 μg/m^3, respectively. The measurements of Cr(VI) during this operation were less than 0.25 μg/m^3. Breathing zone Mn concentrations were similar during grinding and welding.

Matczak and Chmielnicka (Ref. 168) measured 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. Total Cr levels were highest in the two plants in which welding was performed in semi-enclosed areas without local ventilation. Total fume concentration was well correlated with total Cr, total Cr(VI), soluble Cr, and soluble Cr(VI). The overall mean percentages of the elements in breathing zone samples from all four plants combined were 11.2% Fe, 3.9% Mn, 3.6% Cr, 0.5% Ni, and 3.3% F.

Hlavay et al. (Ref. 115) analyzed fumes collected in several Hungarian metalworking shops. Seven welders in an assembly shop were fitted with personal samplers during six 8-hour shifts. The mean respirable dust concentration was 5.52 mg/m^3, and accounted for 58% of the mass of the breathing zone samples. The mean concentration of Fe was 2.2 mg/m^3. The mean concentration of Mn (425 μg/m^3) exceeded the Hungarian maximum allowable concentration of (300 μg/m^3) in samples collected from six of the seven welders.

Kiilunen (Ref. 146) analyzed chromium and nickel exposure of Finnish workers using two large databases that contain data collected during workplace industrial hygiene surveys conducted by the Finnish Institute of Occupational Health. Because the information in these databases came from workplace surveys that were requested and paid for by individual companies, the databases do not cover all Finnish industries, nor do they represent a planned randomized selection of workplaces. The number of analyses conducted was highest in the fabricated metal products manufacturing group; welders and sheet metal workers were the most heavily exposed workers in this group. The first database contained the results of analysis of Ni, total Cr, Cr(VI), and total dust in area air samples collected in 216 workplaces during the years 1980 through 1989. In some cases the only data reported were the number of measurements taken and the number that exceeded the Finnish occupational exposure limits (OELs) for Cr (500 μg/m^3), for Cr(VI) (50 μg/m^3), or for Ni compounds (100 μg/m^3). During the 10 years of this survey, about 9% of all the samples collected were above the OEL for Cr. In the case of welders, the mean concentrations of total Cr (354 measurements), Cr(VI) (290 measurements), and Ni (337 measurements) exceeded the OELs. For all occupational groups, the median concentrations of each of the three metals were below the OEL, indicating that the mean concentrations were affected by a few high readings.

The second database contained the results of analyses of Cr and Ni concentrations in urine collected from workers in the health surveillance programs. The average urinary Cr measurements in all classes of industrial workers over the 10 years of this study exceeded the 95th percentile in the general population (0.01 μmol/L), but most were lower than the Finish biological action limit (BiAL) of 1.0 μmol/L. Table 1 shows the average and the 95th percentile urinary Cr among welders, plasma cutters, and gas cutters. These values exceeded those for all other occupations except for molders, whose urinary Cr concentrations were similar to those of gas cutters. A large fraction of the urinary Ni concentrations measured among the welding occupations were higher than the 95th percentile in the general population (0.2 μmol/L), but most were below the Finnish BiAL of 1.30 μmol/L.

Carrer et al. (Ref. 39) described the result of a biological monitoring program for welders employed in an Italian power plant. Urinary nickel levels in welders were substantially higher than those in the reference population (mean nickel concentrations were 43.2 μg/24 hours in welders and 2.7 μg/24 hours in referents). When urinary excretion levels of other metals (Cr, Zn, Fe, Mn, Cu, Al, and Pb) were measured, only aluminum and lead were elevated, and they only slightly exceeded the corresponding reference values. In response to these results, some adjustments in personal prevention measures were introduced at the workplace. Subsequent tests of metal concentrations in urine indicated a progressive reduction in urinary nickel excretion levels in all welders.

4. Welding with Lasers

High-power CO_2 lasers are widely used for welding, drilling, and cutting metals. Hazards associated with the use of lasers include fumes, electric shocks, direct and reflected radiation, and exposure to the chemicals required for laser operation. Radiation hazards include the invisible IR laser beam itself as well as ultraviolet (UV) and visible light which are released during laser/target interactions. Hietanen et al. (Ref. 111) evaluated radiation and chemical hazards associated with CO_2 lasers. The intensity of scattered or reflected laser radiation and concentrations of welding and cutting fumes were

Table 1
Concentrations of Chromium and Nickel in Post-Shift Urine of Finnish Welders and Cutters (1980–1989)

	Cr Concentration µmol/L (BiAL[a] = 1.0 µmol/L)		Ni Concentration µmol/L (BiAL[a] = 1.3 µmol/L)	
	Mean (n[b])	95th Percentile	Mean (n[b])	95th Percentile
General population	—	0.01	—	0.20
Welders	0.23 (2580)	0.91	0.19 (708)	0.42
Plasma cutters	0.31 (52)	0.97	0.27 (29)	0.62
Gas cutters	0.25 (133)	0.70	—	—

a. BiAL is the Finnish biological action level for the element in urine.
b. n = number of measurements.
From Kiilunen (Ref. 146).

determined during welding, cutting, and thermal treatment of aluminum, carbon steel, and stainless steel. The results indicated that diffuse reflection of the laser beam was small during normal operations but substantial scattered radiation resulted from a misdirected beam. Permissible exposure times were calculated, as described previously (Ref. 112) from the recorded irradiances, maximum permissible exposures, and recommended threshold limit values (TLV). Permissible exposure times based on UV radiation were shortest for stainless steel welding (95 seconds) and carbon steel welding (124 seconds). For blue light exposure, the recommended maximum exposure time for unprotected eyes was 11 minutes for stainless steel welding. The investigators concluded from this that scattered laser radiation, noncoherent UV radiation, and blue light must be considered when selecting eye protectors. The risks could be reduced by decreasing work time near the laser beam, by avoiding reflective surfaces at the workstation, and by using appropriate eye protection.

Welding fume particles were less than 0.5 µM in diameter and were oxidized condensation products of the materials used. Fumes generated by welding carbon steel were composed mainly of iron oxides. Hexavalent chromium was undetectable (<0.007%) in fumes generated by welding stainless steel and varied from 0.12 to 0.6% in fumes from cutting stainless steel. The fume generation rates for welding and cutting of carbon and stainless steel are shown in Table 2. The fume generation rate for laser beam cutting of stainless steel was comparable to that for GMAW, and was about ten times higher than that for laser welding of stainless steel (Ref. 112).

Kokosa (Ref. 151) listed some of the hazardous substances that may be formed when processing materials with lasers. Industrial lasers operate at wavelengths that are absorbed by the material being processed. The absorbed energy is translated into heat, producing a high-energy plasma above the part being cut or welded. The temperature of this plasma may reach 10 000°C which melts and vaporizes the metal. The metal vapors may react with the atmosphere surrounding the weld and then condense to form an aerosol as they leave the high-temperature region of the plasma. The author cited an unpublished study in which it was found that Cr(VI) was formed during cutting of Type 304 stainless steel.

Haferkamp et al. (Ref. 99) investigated the rates of aerosol and slag emissions from metal and plastic cutting with a 1-kW laser and welding with a 5-kW laser. Gas emissions from cutting metals were negligible. Slags and aerosols accounted for greater than 100% of the mass lost in cutting, due to oxidation of the metals in the surrounding air. Aerosols accounted for between 5 and 20% of the mass lost, and the aerosol generation rate was between 1 and 35 mg/s, depending upon the material being cut, its thickness, the focus lens, and the cutting speed.

4.1 Hazards Associated with Lasers. Lasers are classified under the U.S. Federal Laser Performance Standard according to their biological hazards. The power of a Class IV laser, rated the most hazardous, is required for welding and cutting of metals. 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.

Table 2
The Fume Generation Rate (FGR) During CO_2 Laser Beam Welding and Cutting of Carbon and Stainless Steel

Operation	Material	FGR (g/hr)	FGR Range (g/hr)	No. of Observations
Welding	Carbon steel	4.36	3.46–6.01	14
Welding	Stainless steel	4.59	3.19–60.2	17
Cutting	Carbon steel	27.37	17.6–46.2	17
Cutting	Stainless steel	45.41	20.9–92.3	19

Data from Hietanen, Ref. 110.

Skin injuries accounted for 10% of the reported injuries. The persons most often injured were technicians servicing the laser. Workers using the laser equipment were the second most often injured. The CO_2 laser and the Nd:YAG laser are the two types of lasers most commonly used in welding. The CO_2 laser has been in popular use for a longer time and is typically more powerful than the Nd:YAG laser, but the Nd:YAG laser accounted for 27.5% of the accidents and the CO_2 laser was involved in 14.9%. One reason for this is that the Nd:YAG laser operates at a wavelength in the near IR that more readily damages the eye than does the far IR wavelength of the CO_2 laser.

5. Electromagnetic Fields

Weman (Ref. 279) reviewed the mechanisms by which electromagnetic fields (EMFs) are produced by welding equipment and discussed the EMF exposures specific to various types of welding. Magnetic fields produced by electricity flowing through a wire or cable are usually canceled by the fields produced by the return line. Because welding cables tend to be separated, the EMFs are not cancelled out, and the high current used in arc welding produces a relatively large magnetic field. Welding equipment is often close to the welder, and the welding cables may be in contact with the body. The direct current used in GMAW is less likely to produce high levels of electromagnetic radiation than the alternating current used in SMAW and resistance welding, but minor alternations or pulsations in direct current are often produced by a generator which could increase the strength of the magnetic field. The alternating current used in SMAW produces relatively high magnetic fields, but the most powerful electromagnetic fields are created during resistance welding, which uses currents as high as 10 000 amperes (A), and produces magnetic fields greater than 1000 microtesla (μT). In comparison, a worker in a normal office environment may be exposed to EMF with an intensity of 1 μT. Weman recommended that welders' exposure to EMFs be more routinely monitored and that steps be taken to minimize exposure to EMFs from welding. These include screening magnetic fields, laying cables in parallel, positioning EMF-generating equipment at a distance from workers, and equipping power sources with filters to minimize leakage of EMFs.

Bracken (Ref. 37) reviewed efforts to characterize electric field and EMF exposure from industrial sources. In a study sponsored by the Electric Power Research Institute (Ref. 36), magnetic fields were measured in workplaces which did not include welding. In one part of that study, a DC arc welder was fitted with a meter that continuously monitored and recorded his exposure to low-frequency EMFs throughout a workday. The variability of the exposure can be seen in Figure 1 which shows the plot of the EMF to which he was exposed. His peak exposures exceeded 10 μT, and exposures greater than 5 μT were encountered during 5% of the day. His median exposure to EMFs was 0.7 μT.

Szuba (Ref. 256) calculated steady-state EMFs generated by welding and verified them with laboratory measurements. He also referred to the problem of measuring instantaneous exposure to more intense EMFs. The impulse field generated when switching the welding equipment on and off could not be measured by his instrumentation. Szuba noted that there is little information in the literature about the biological effects of exposure to impulse magnetic fields. As more becomes known about how EMFs may interact with human tissues, it should be possible to characterize exposures in a more meaningful way, such as time exposed above a certain threshold, as opposed to cumulative daily exposure, and

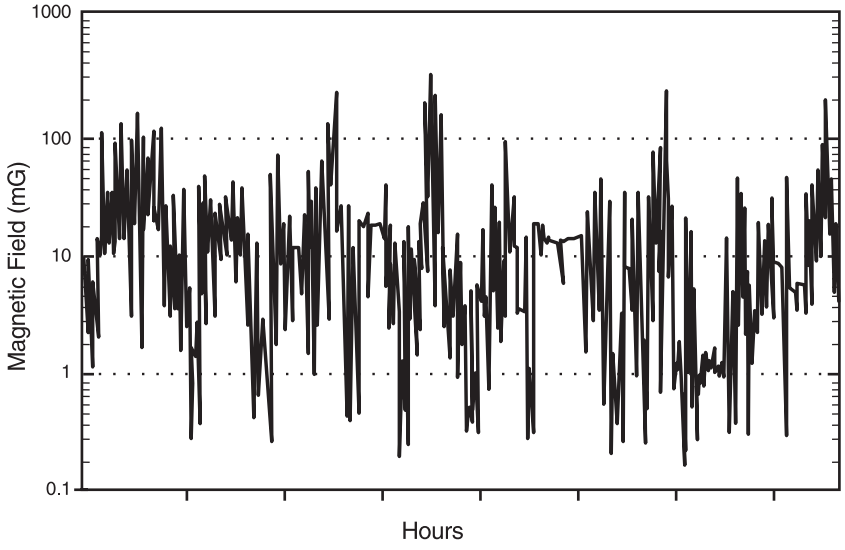


Figure 1—Extremely Low-Frequency Magnetic Field Exposure Measurements for a DC Arc Welder During a Full Workday (Ref. 37)

to design appropriate schemes to monitor and control worker exposures.

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 GTAW are about 10 000 times the maximum permitted levels in the proposed industrial standard. The author predicted that all current GMAW processes will also produce unacceptable EMF emissions. General recommendations to reduce EMF emissions included enclosing cables within metallic conduit, keeping the cables as short as possible, and grounding of equipment. These recommendations parallel those of Weman (Ref. 279) which were directed at reducing workers' exposure to EMFs. Attenuation of EMF emissions to reduce electronic interference will also reduce the potential for adverse health effects from these emissions.

Marco et al. (Ref. 164) evaluated the effect of EMFs from welding on the operation of cardiac pacemakers. A 1500 A industrial spot welding machine interfered with pacemaker operation, but arc welding machines of 225 A or less did not. At intermediate welding currents, some pacemakers encountered interference, and others did not. 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, a device to prevent ventricular fibrillation. The EMFs measured in the patient's workplace, using a field strength measurement system while the arc welder was operated at the upper end of the operational range (200 A and 30 V) were 100 to 300 μT. A spot welder produced stronger fields (500 to 1000 μT). Telemetered cardiac measurements showed no inappropriate marker pulses or other interference with operation of the defibrillator, even when the patient stood close to the transformer used with the spot welder. Embil et al. also noted spikes in the intracardiac electrogram, which corresponded to occasions when the spot welding apparatus was switched on, but there was no corresponding interference with cardiac activity. The patient was advised to return to work and had no untoward experiences over a one-year follow-up period. The authors cautioned that these findings are applicable only to the welding equipment tested, and that the general ability of patients fitted with electronic cardiac devices to work in the presence of strong EMFs remains uncertain.

6. Incidental Exposures

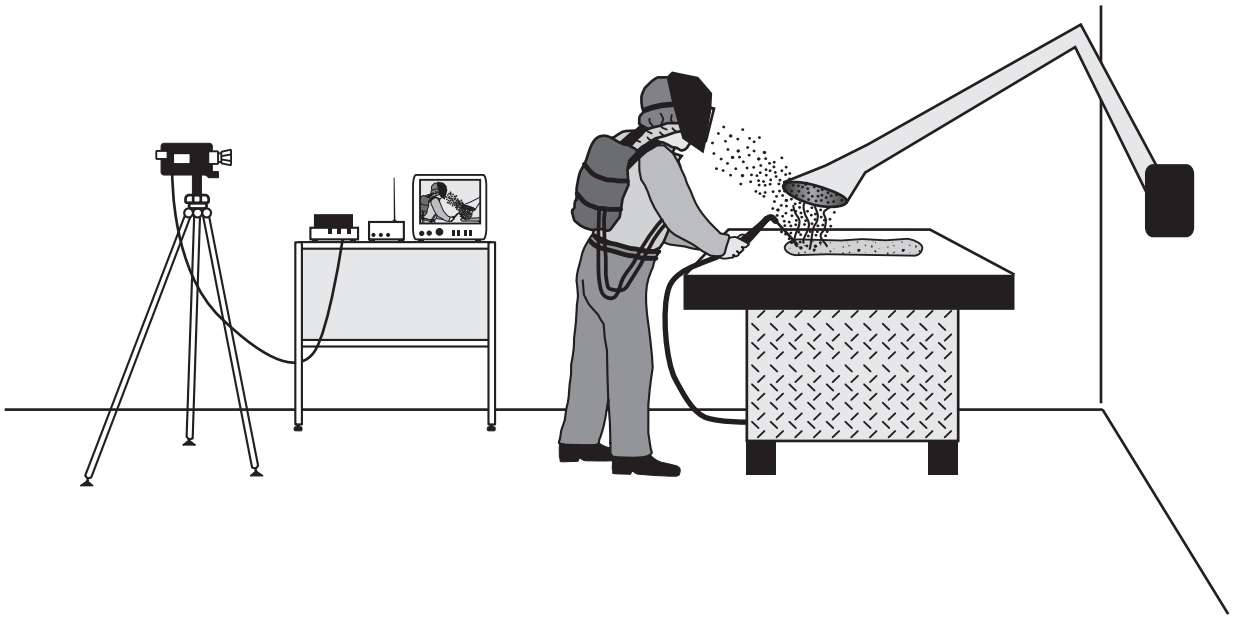
6.1 Production Coatings. Oils are used for corrosion control and for lubrication in the processing of rolled steel. Berger (Ref. 18) measured the pollutants generated from spot welding of oil-coated steel sheets. Airborne

concentrations of oil mist and oil vapors, as well as those of iron oxide, zinc oxide, and copper, were measured, with and without ventilation, during spot welding in automated lines, and during the use of spot welding machines and hand-held welding guns. Oil mist concentrations ranged from 0.10 to 0.24 mg/m^3 for spot welding in the automatic lines, from 0.20 to 0.70 mg/m^3 when using the spot welding machine, and from 0.16 to 0.80 mg/m^3 when using the spot welding gun. Oil vapor concentrations were similar to mist concentrations. None of the pollutants measured exceeded the German workplace limits, but the levels were generally highest when welding was performed with hand-held welding guns. Local ventilation was usually successful in reducing pollutant levels. However, Berger noted that volatile material, which may continue to be emitted from the weld and from discarded parts after welding is completed, could escape removal by local ventilation at the welding site. In order to minimize oil mist in the workplace, Berger recommended that oil coatings be reduced to the minimum necessary for corrosion prevention and for lubrication in rolled steel operations. He also recommended that oil should be removed from areas to be welded; this is particularly important when oil has pooled in depressions in the parts to be welded.

6.2 Thermal Exposure. Ambient temperatures during welding in a brassware factory in Morabadad, 100 miles east of Delhi, India, averaged 41.1°C (106°F), as measured by Rastogi et al. (Ref. 212). The globe temperature, a measure of temperatures attained as a result of thermal radiation, averaged 50.3°C (122.5°F).

7. Hygiene and Work Practices

7.1 Training. The "Picture Mix Exposure" (PIMEX) system, first described by Rosen and Lundstrom 1987 (Ref. 221), couples videotaping of workers with direct-reading instrumentation of breathing zone exposures. The resultant videotape of work practices with a superimposed presentation of real-time exposure data has been used to evaluate the relationship between exposures to fumes, dusts or solvents and individual work patterns as well as to train persons who work with hazardous substances. Figure 2 shows how the PIMEX has been applied to the evaluation of local exhaust systems in controlling exposures to welding fumes. The PIMEX system has been used for studies of worker behavior, for modeling exposure to airborne contaminants, and for the development of technical control procedures. This



The real-time monitoring instrumentation for measuring breathing zone fume exposure is carried in a backpack by the welder. The working habits of the welder are recorded with a video camera and the output signals from the exposure monitor and the camera are fed into a video mixer which produces the combined video that shows the welder at work and the breathing zone exposures received as he is working.

Figure 2A—The PIMEX Method for Study of Worker Exposure to Welding Fumes (Ref. 220)

The bar graph at the left represents the current exposure. Measurement range, date, and time are shown on the bottom.

Figure 2B—Presentation of Worker Exposure in the Combined Video Picture (Ref. 220)

method was recently used (Ref. 220) 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. The PIMEX system was then used to train the welders on proper usage of the exhaust equipment (Refs. 219 and 220).

7.2 Ventilation. Nygren and Nordstrom (Ref. 191) examined the effects on air quality of energy-conserving changes in local ventilation that had been made in two Swedish welding workshops. Industrial hygiene measurements were taken in the two plants before and after each workstation was equipped with computerized controls that activated supply and exhaust ventilation only when welding was being performed. In the first company, where welding and cutting of mild steel were carried out in compartmentalized workshops, the mean dust concentrations in general area samples had decreased following modifications of the ventilation system, but there was a nonsignificant increase in the mean dust concentrations in personal samples. In the second plant, which employed SMAW of stainless steel almost exclusively, all mean dust concentrations were significantly reduced. There was also a significant reduction in the mean and maximum Cr(VI) concentrations at all of the workstations sampled before and after modifications were made. One measurement of Cr(VI) in excess of the Swedish OEL of 20 $\mu g/m^3$ was made at a workstation that had not been surveyed before modification had occurred. The authors regarded this as an example of excessively high exposures that may sporadically occur even with adequate general ventilation. The authors concluded that reductions in energy consumption could be achieved by changes in workplace ventilation systems without decreasing the air quality at the workstation.

7.3 Protective Gear and Equipment. Sutter (Ref. 252) discussed the specifications for welding screens and curtains to protect non-welders and passersby from UV and IR radiation. Opaque screens provide maximum protection, but they interfere with communication among workers and they may prevent observation of accidents. Using published measurements of radiation from arc welding, Sutter calculated the degree of radiation reduction necessary to protect nearby personnel from radiation throughout the spectrum from UV to far IR. Radiation from electric arc welding is generally stronger than that from oxyfuel gas welding, and the intensity of the radiation emitted during welding increases with the electric power used by the welding equipment. Radiation is maximized in the UVB region with high-powered equipment, and the maximum protection is required for workers. Much less protection is required in the UVA region. To protect against radiation from arc welding in the workplace, transmission through protective curtains in the visible-to-UVB range should not exceed 10%. Sutter indicated that a transparent gray welding screen would be sufficient for most electric arc welding processes. For oxyfuel gas welding, a transparent orange screen is sufficient for 1000 seconds of observation at a distance of 2 meters. Sutter recommended the use of opaque screens when observation and supervisory control are not the most important factors in the workplace.

Sutter and Ott (Refs. 253 and 254) investigated the temperature increase in eye-protective filters during welding. Mineral glass filters without protective coatings can reach temperatures of 100°C. These temperatures are high enough to burn the welder and can also damage synthetic materials used for eye protection. Extremely thin evaporative coatings of gold have been used to reflect IR radiation and thus provide protection against thermal injury. These coatings are transparent to light in the visible range, but reflect IR radiation. To avoid the high cost of gold, manufacturers have produced filters with coatings of other materials. The authors devised laboratory equipment and tested 62 filters from five manufacturers. They found a good correlation between the reflectivity of the filter and the temperature attained by the filter. Unclad filters provided sufficient protection for radiation less

than 250 W/m^2. At 450 W/m^2, reflective filters clad with either silver or gold attained a temperature of 33° to 35°C, while unclad and grey filters reached 40° to 45°C. At 1800 W/m^2, unclad and gray filters reached temperatures in excess of 80°C in 5 minutes, while silver and gold clad filters reached 60°C. The authors concluded that high-grade silver and gold coatings are effective protection against thermal buildup in the filter, while coatings of other materials are not a worthwhile improvement over unclad filters.

7.4 Accidents. Suruda and Smith (Ref. 251) reported that there were 33 electrocution deaths involving portable arc welding equipment in the databases of NIOSH and OSHA for the years 1984 through 1986. The primary 220- to 440-V electric circuit was reported as the source of electrocution in ten cases. In none of these cases was the welding apparatus grounded. The welding electrode or another part of the secondary circuit was involved in an additional ten deaths. Thirteen deaths involving welding apparatus were reported in which there was insufficient information to implicate the circuit involved. The authors concluded that all of these deaths could be have been prevented by effective administrative and engineering controls.

The details of fatal accidents involving ironworkers in the U.S. were examined by Hardesty et al. (Ref. 103). During the period 1985 to 1989, 185 fatalities that occurred among workers in steel building and plant construction, resulted from falls from elevation. Of these, 44 occurred during welding or bolt-up operations. Setting and connecting steel prior to these operations accounted for nearly the same number of fatalities.

Davie et al. (Ref. 60) studied case reports of 73 accidents that occurred in heated bitumen storage tanks in the United Kingdom during the years 1971 through 1992. There was no discussion of any injuries resulting from these accidents. Bitumens are viscous liquid or solid hydrocarbons produced by petroleum refining processes or found as natural deposits or as components of naturally occurring asphalt. Flammable atmospheres can exist within the vapor space of bitumen storage tanks, and pyrophoric materials have been found on the roofs of some tanks containing these materials. Nine of the accidents occurred during welding or while using a blow torch to heat a plugged line. Two cases were summarized. In the first, an explosion was detonated inside a tank while welding was performed on the outside. The cause was traced to an improper ground which had allowed current from the welding machine to flow into the tank. In the second case, a fire occurred when sparks from welding operations ignited vapor in a new 36 cubic meter electrically heated bitumen storage tank. The tank was being used before the installation had been completed.

Section Two
Effects of Welding on Human Health

8. Respiratory Tract

8.1 Pulmonary Function. Lung function tests are often used to compare the pulmonary function of welders with those of workers who were not exposed to welding fumes. Pulmonary function tests may also be used to monitor changes in respiratory function over the course of a welder's career. Lung function tests are usually conducted using a spirometer, which measures volume and flow rates of exhaled air. Some of the more widely used of these tests are defined in Table 3. Lung function tests are sometimes performed after administration of suspected allergens from the workplace or nonspecific provocative agents such as methacholine and histamine to detect hyperreactivity in the respiratory tract, which may be indicative of asthma. Because of wide intersubject variability, these tests are not as useful for definitive diagnosis of disease in patients as they are for following the progress of disease or for comparing the average lung performance in groups of workers exposed to known or suspected pulmonary irritants with that of unexposed controls. Some investigators have used equations based on the subjects' heights, weights, and other anthropometric measurements to normalize lung function measurements among exposed and unexposed groups (Refs. 41 and 87).

Because the wide range in inter-individual pulmonary function test results can make it difficult to assess the meaning of individual lung function tests, it is valuable to obtain pre-exposure values or baseline levels of pulmonary function before an individual is exposed to materials which may damage the respiratory tract. Comparison of preemployment values with those obtained during employment can then be used to assess whether or not declines in lung function have occurred. Such tests are frequently administered in preemployment examinations.

Chinn et al. (Ref. 41) explored whether preemployment examination at age 16 or 17, before lung capacities have reached their adult potential, may be useful for monitoring lung function in young adults. They compared pre-employment lung function tests of 114 nonasthmatic males, who began work as apprentices in an English shipyard at age 16, with subsequent measurements taken through ages 25 to 27. Forty-nine of the apprentices were trainee welders or caulker burners. Additional measurements were available at age 21 for 84 of the subjects. Changes in body measurements between

Table 3
Common Measurements of Pulmonary Function

Test	Abbreviation	Notes
Forced Vital Capacity	FVC	Maximum volume of air that can be exhaled after a maximum inhalation. FVC is reduced in restrictive lung disease* and to a lesser extent in obstructive disease.*
Residual Volume	RC	Air remaining in lung after maximum exhalation.
Total Lung Capacity	TLC	Sum of FVC and RV.
Forced Expiratory Volume	FEV_1	Volume that can be exhaled in one second with maximum exertion. Normally about 80% of FVC. FEV_1 is reduced in restrictive lung disease and in obstructive lung disease.
FEV_1 as Percent of FVC	FEV_1/FVC	Reduced in obstructive lung disease, normal or slightly increased in restrictive lung disease.
Volume of Trapped Gas	VTG	Increase in VTG is a sensitive indicator of asthma.
Forced Expiratory Flow Rate	FEF $FEF_{25–75}$ $FEF_{75–85}$	Measured during exhalation: Mid-range (25–75%). Terminal flow (75–85%). Reductions in $FEF_{75–85}$ indicate impairment in small airways (alveolar region of the lung).
Maximum Expiratory Flow	MEF_{25} MEF_{50}	Measured at 25% of FVC. Measured at 50% of FVC.
Peak Expiratory Flow Rate	PEFR	Peak momentary expiratory flow rate during maximum exhalation. Subnormal or declining values in PEFR are indicative of asthma.
Closing Volume	CV	The amount of nitrogen exhaled during the final phase of a resident nitrogen closing volume test, after the point where the basal airways are believed to be closed. An increased CV is regarded as a sensitive indicator of airways disease.

*Obstructive lung disease affects airflow through the airways and includes pathological conditions such as bronchial asthma, chronic bronchitis and emphysema. Restrictive lung disease affects diffusion of gases through the lung parenchymal tissue and includes conditions such as interstitial lung disease and diffuse pulmonary fibrosis.

ages 16 and 25 to 27 years accounted for about half of the extent of changes seen in the forced expiratory volume in 1 second (FEV_1), the forced vital capacity (FVC), and the total lung capacity (TLC). By age 21, FEV_1, and residual volume as percent of TLC had attained their adult values. The authors concluded that lung function tests at age 16 have a long-term significance, nearly as great as those for age 21 and, thus, should be preserved for future comparisons.

In many epidemiology studies of lung function, exposure histories are obtained using self-administered questionnaires or by interviews of the subjects without reference to documented work histories. Van der Gulden et al. (Ref. 266) examined the reproducibility of self-reported data on occupational exposure to several specific airborne substances, including welding fumes. Subjects were interviewed by telephone 3 to 5 weeks after returning a mailed questionnaire. In general, there was good agreement between questionnaire responses and telephone interviews. For welders, an 80% agreement was found between the responses to the two types of interrogation. The authors concluded that self-reported exposures can be used in epidemiological studies when objective information on occupational exposure is not available.

In 1981, Mur et al. (Ref. 186) conducted a cross-sectional epidemiological study in a factory that produced industrial trailers and semitrailers. The frequency of respiratory impairment, as measured by X-rays and spirometry, was greater among welders than among nonwelders in the same factory. The same population was reexamined 5 years later (Ref. 185) at which time the subjects completed respiratory symptom questionnaires and were subjected to physical examinations, chest X-rays, and lung function tests. A carbon monoxide (CO) lung transfer test was also carried out to determine the fractional uptake of CO (FuCO). Subjects who had begun or stopped welding or had changed their smoking

habits after the initial study was completed were excluded from the follow-up study. The population remaining in the study and tested in 1986 consisted of 138 active GMAW welders (82 welded mild steel exclusively) and 106 non-welding controls. In the follow-up examinations, there was a significant decrease in the maximum expiratory flow (MEF_{25}) in the nonsmoking welders compared with nonsmoking controls. Even though this difference was not significant in the 1981 examination, the rate of decline in lung function during the 5-year period 1981 to 1986 did not differ significantly between the nonsmoking welders and nonsmoking controls. In both 1981 and 1986, the FuCO among smokers who welded mild steel was significantly lower than that among smoking controls.

Nielsen et al. (Ref. 190) studied small airways respiratory function in 25 Swedish male welders who performed GMAW and GTAW of aluminum and SMAW of stainless steel. The two metals were welded in different workshops. A control group of 25 males, matched for age and smoking history, was recruited from a wine warehouse. Exposures to total dust, aluminum, Cr(VI), ozone, and oxides of nitrogen were measured in the breathing zone of 19 of the welders and were all below the Swedish occupational exposure limits (OELs). Blood samples were taken and analyzed for immunoglobulins. There were no differences between welders and controls with respect to the serum immunoglobulins IgE, IgG, or IgM, but IgA levels were significantly lower in welders. Urine samples from 19 of the welders were analyzed for aluminum at the beginning and the end of the workweek. The urinary aluminum levels in the welders were increased in samples collected on Monday morning and Friday after work compared with that in controls.

Spirometry was performed to determine FVC, FEV_1, and MEF_{75}. Small airways function was measured both before and after provocation with methacholine using two tests (VTG and closing volume) based on nitrogen washout from the lungs. The nitrogen washout test after methacholine provocation showed significant changes in the alveolar (small airways) portion of the lungs of the welders compared with the controls. The change in the small airways after methacholine provocation was significantly greater in welders with at least 2.5 years experience than in welders with less experience. No other significant findings in lung function were found. The authors concluded that welding fume exposure may have induced an increase in the reactivity of the small airways.

Nakadate et al. (Ref. 188) performed pulmonary function tests on three cohorts of healthy male workers: 123 workers who were currently exposed to asbestos dust at levels below the Japanese OEL of 2 fibers chrysotile/mL, 213 workers who were exposed to welding fume levels below the OEL of 1 mg/m^3 respirable dust, and 148 workers without discernible exposure to either welding fumes or asbestos. Welders showed significant increases in FEV_1 and FEF_{25}, compared with the two other groups.

Gennaro et al. (Ref. 87) evaluated data from a study of lung function in Italian shipyard workers that had been conducted in 1982 and 1983. Of the 657 males who volunteered for the study, 49 were oxyfuel gas welders and 36 were arc welders. Lung function (FEV_1 and FVC) had been measured using a pneumotachograph. The normal range of these lung measurements was calculated for each of the subjects as a function of age, height, and weight (Ref. 53). Obstruction was defined as normal FVC and low FEV_1/FVC and restriction was defined as low FVC and low FEV_1/FVC. Odds ratios (ORs) were calculated by dividing the incidences of obstruction and restriction in each of the job classifications by their incidences in the reference population of metalworkers, who worked outside on scaffolding and were considered to be the shipyard workers least exposed to respiratory tract irritants.

Lung restriction, but not lung obstruction, was significantly increased among welders (gas welders: OR = 3.58, CI = 1.45–8.86; arc welders: OR = 4.14, CI = 1.50–11.44). The authors noted that if the effects of welding fumes are principally on the small airways, then the pulmonary function tests, which primarily reflect large airways resistance, may not have revealed welding-induced obstructive impairment.

Panjawani (Ref. 199) reported results of lung function tests of 41 male welders who had more than 10 years experience welding and nine unexposed male controls. None of the controls and 18 of the welders were smokers. Compared with controls, FVC was reduced only in smoking welders, and heavy smokers showed both pulmonary obstruction and pulmonary restriction. FEV as a percentage of FVC was reduced in all welders, as was FEF. The statistical significance of these findings was not discussed.

A study of pulmonary function in 229 male welders in Montreal, Canada, conducted by Rossignol et al. (Ref. 223), compared results of spirometry tests and self-reported pulmonary symptoms at the start and end of a 5-year period. During this time, the average annual decline in the forced FEV_1 was 41 mL and the ratio FEV_1/FVC was 0.4.

Hjortsberg et al. (Ref. 114) measured respiratory function in 14 arc welders who worked in a Swedish shipyard and in 14 white-collar controls who had not been exposed to welding fumes. None of the study participants were smokers or reported having allergic symptoms (i.e., they were nonatopic). They were all free of pulmonary diseases or symptoms and had normal chest X-rays. This study population was selected to avoid the confounding effects of tobacco use and atopy found in a

previous study of a different population of shipyard workers conducted by Chinn et al. (Ref. 42). Asbestos had been used in the shipyard for many years, so indirect exposure to asbestos could not be ruled out. The major finding was a significant increase in VTG among the welders. VTG measured before and after inhalation of methacholine and after inhalation of salbutamol was consistently elevated in the welders, and the ratio of VTG/TLC was more markedly elevated. No difference in FEV_1 was found between welders and controls. These results were suggestive of hyperreactivity in the small airways and possibly asthma in the welders. The authors contended that self-selection of welders out of that occupation when they develop respiratory difficulties tends to make their findings an underrepresentation of small airways dysfunction among welders.

Mohan et al. (Ref. 177) measured FEV_1, FVC, and CO uptake among a group of 80 male and two female welders, median age 59, who had sought compensation for "welders' lung." Of these, 33 were assessed by a physician as having asthma or possible asthma. Eighteen of the welders had a greater than 15% reduction in FEV_1, and 10 had a 10–15% reduction, compared with predicted values.

Three groups of investigators observed that reversible changes in lung function may occur during a single day of welding (Refs. 2, 57, and 62). Akbar-Khanzadeh (Ref. 2) measured FVC, FEV_1, and the lung transfer factor for CO in 209 shipyard welders and 109 non-welding controls before and after the workshift for a full week. Each of the welders completed a form detailing his welding exposures and the ventilation used while welding. Breathing zone samples of particulates and gases were collected using personal samplers stationed behind the welding face guard. The mean ages and smoking habits of the welders and the controls were the same. Time-weighted average concentrations of CO, oxides of nitrogen, and particulate fumes were significantly greater in the breathing zones of welders than in samples taken in the work area of the controls.

Pulmonary function indixes declined significantly during the workshift in both welders and controls but the severity of the decline and the proportion of workers who experienced the decline was greater in welders than in controls. The reduction in all of the lung function indixes among welders was approximately four times greater than that in controls. Breathing zone concentrations of iron oxide exceeded the OEL of 5 mg/m^3 in 6.7% of the samples, and they were significantly associated with the reduction in FEV_1 in welders. The lung function test data were also analyzed with respect to the welding location, ventilation used, and electrode type and diameter. Of these, only ventilation showed a significant effect. 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. Akbar-Khanzadeh concluded that, although his study did not provide sufficient evidence to prove an association between exposure to welding fumes and decreased lung function in welders, the possibility that acute respiratory changes result from exposure to welding fumes warrants further study.

Dahlqvist et al. (Ref. 57) measured lung function in 28 welders after a 2-day weekend break from welding, after a day working with a respirator that provided filtered air, and after a day working without a respirator. In each of the three companies in which the study took place, gas shielded flux cored arc welding (FCAW-G) of low-alloy steel was performed using CO_2 or argon-CO_2 as the shielding gas. All of the welders were fitted with breathing zone samplers for total and respirable dust.

FVC and Peak Expiratory Flow Rate (PEFR) were significantly lower among the welders after they had worked without a respirator than they were after two days of no exposure. The decrease in FVC at the end of the workshift was correlated with exposures to both total and respirable dust. Lung function did not decline during the workshift when the welders used respirators.

In the third study of the acute effects of welding upon lung function, Donoghue et al. (Ref. 62) measured the PEFR before, during, and after a Monday work shift in 20 welders and 20 assembly and maintenance workers in New Zealand. All of the subjects tested were nonsmokers, and none reported a history of asthma. GMAW, SMAW, and GTAW were performed on mild steel by 16 welders and on stainless steel by four welders during the shift.

After the first 15 minutes of welding, 50% of the welders, and only 5% of the non-welders, had a 5% decrease in PEFR. (A 20% decrease in PEFR which would be indicative of asthma was not found in any of the subjects tested.) The average decrease in PEFR was significantly greater among the welders than among the non-welders. None of the subjects reported respiratory discomfort during the shift. No correlation was found between decline in PEFR and either years of welding experience or hours of welding on the day of the study. The authors concluded that "a statistically significant, immediate, reversible airways obstruction was found in workers welding on a Monday morning." They recommended that further studies of this effect should be conducted and should include measurement of breathing zone concentrations of particulates, metal fumes, and irritant gases.

8.2 Asthma and Bronchitis. Wanders et al. (Ref. 275) conducted a 40-year historical cohort study of Dutch

shipyard welders. The primary hypothesis tested was that medical disability due to musculoskeletal disorders would be higher among welders than among controls employed in the same shipyard — see discussion in Subsection 16, Effects on the Musculoskeletal System. The secondary hypothesis of the study was that the incidence of respiratory diseases would be elevated among welders. The controls were shipwrights and engine fitters who were employed at the same shipyard as the welders between 1946 and 1986, the endpoint of the study. Workers were not interviewed or examined.

"Wastage," the variable representing medical disability, consisted of any of the following: permanent disability, death, job transfer due to medical reasons, and voluntary or involuntary retirement or discharge due to disability. Since medical diagnoses related to disability were not recorded before 1966, only the 108 welders and 255 controls who retired with disability between 1966 and 1986 were included in the study.

A significantly higher proportion of diagnoses of nonmalignant respiratory disease was found among the welders (incidence ratio = 3.15, 90% CI = 1.57–6.31) compared with the controls. While there were no controls for smoking, the authors stated that the incidence ratio for respiratory diseases was too large to be fully explained by differences in smoking habits between welders and controls.

Hansen and Skytthe (Ref. 102) conducted a study of respiratory problems in welders, grinders, and other metal workers. The study group consisted of 7582 male stainless steel and mild steel welders, stainless steel grinders, and non-welding and non-grinding metal workers in 79 Danish welding companies. The subjects completed a postal questionnaire in 1986 specifying lifetime occupational exposures, smoking and drinking habits, and respiratory symptoms. Metal workers (including welders) whose job activities included grinding stainless steel had a significant excess of chronic bronchitis and asthma symptoms. Exposure to welding fumes was also significantly associated with symptoms of chronic bronchitis and asthma. Smoking and asbestos exposure were confirmed as major risk factors for chronic bronchitis. The authors concluded that exposure to grinding dust is a critical risk factor for chronic bronchitis and asthma symptoms. Welding fume exposure was considered a less important risk factor.

Antti-Poika et al. (Ref. 10) conducted a case-control study of occupationally related asthma among identical twins. The study population included 58 nonasthmatics and 78 asthmatics. All the cases with asthma had developed the condition after age 18. The participants responded to questionnaires concerning asthma, detailing exposure to a list of 30 common allergens and potential occupational exposures to respiratory allergens and irritants.

Thirty-one pairs of twins were discordant with respect to asthma (i.e., only one of the twins had asthma). A pairwise analysis of occupational exposure and smoking with respect to asthma among the discordant pairs of twins indicated that only smoking and exposure to organic solvents were significantly greater among the twins that had asthma than among the ones that did not. Welding in general, and welding of specific metals, were included in this portion of the study, with negative results. When the entire population of twins in the study was considered, welding was again not found to be a significant contributor to the development of asthma. The authors stated that the small size of their study population made it unlikely that conspicuous differences would be found.

Hunting and Welch (Ref. 123) examined the relationship between lung disease and exposure to fiberglass or asbestos in sheet metal workers. In order to reduce the influence of exposure to welding fumes, workers were excluded if they reported having welded for more than 20% of their working careers. Workers were chosen from 19 Sheet Metal Workers International Association locals that reported high use of fiberglass. The 407 subjects selected had participated in a previous medical screening in 1986 to 1988, which included a self-administered questionnaire, a physical examination, spirometry, and chest X-rays. In 1990 and 1991, telephone interviews were conducted with 333 of the subjects who provided detailed information on exposure to fiberglass and asbestos. The percentage of time spent welding or in the vicinity of welding was also reported, as was work outside the sheet metal trade. The participants had worked in the sheet metal trade for an average of 34 years. The median equivalent exposures to fiberglass and asbestos were 12 and 5 years, respectively, and 23% of the participants had cumulative welding exposures of five or more years.

Cigarette smoking was strongly related to development of both chronic bronchitis and obstructive lung disease. A significant increase in risk for chronic bronchitis, but not obstructive lung disease, was also found for years of exposure to asbestos and to fiber glass. Welding exposure of 4 or more years was correlated with obstructive lung disease compared with non-welders in the same population (OR = 4.09, CI = 1.27–13.22).

Wang et al. (Ref. 276) compared the incidence of asthma among stainless steel and mild steel welders in four factories in Sweden. To compensate for the self-selection bias caused by welders afflicted with lung disease leaving the profession, both former and active welders were included in the study. The welding cohort consisted of 26 active and 16 retired stainless steel welders, and 37 active and 48 retired mild steel welders. The average age

of the welders was 28 years and they all had welded for at least 6 months during the 10 years preceding the start of the study but had not been employed as welders prior to that time. Six of the retired stainless steel welders and ten of the retired mild steel welders cited airway symptoms as a main reason for leaving work. The 26 controls were active vehicle fitters from one of the four factories (mean age 29 years) who had never worked as a welder and had no symptoms or history of asthma.

Exposure conditions were investigated in three of the factories. Breathing zone concentrations of total fume, chromium, manganese, and nickel in air samples collected inside the helmets of some of the welders are shown in Table 4. Workshop levels of oxides of nitrogen and ozone were consistently below permissible occupational limits. Two of ten stainless steel welders were exposed to fume concentrations in excess of 5 mg/m^3.

All of the welders and ex-welders were given questionnaires regarding respiratory symptoms. Analysis of reported symptoms showed that the presence of phlegm was significantly more prevalent among welders of both stainless and mild steel than among the vehicle assemblers, and a significant increase in dyspnea (shortness of breath) was seen in the active stainless steel welders and in the mild steel ex-welders compared with the controls. The prevalence of reported symptoms was the same in mild steel and stainless steel welders.

Twenty-three of the active stainless steel welders, 23 of the active mild steel welders, and the 26 non-welding controls were tested for asthma by lung function tests, by the single breath nitrogen test, airway resistance tests, and FEV_1 after methacholine challenge. Results of the lung function and bronchial responsiveness tests with methacholine were normal and showed no significant differences between the stainless and mild steel welders or between welders and controls.

Ex-welders who reported airway symptoms were tested by spirometry and bronchial provocation tests unless medical records gave a clear diagnosis. These tests showed that one active and one ex-welder out of 42 stainless steel welders and one active and two ex-welders out of 85 mild steel welders had developed symptoms of asthma while welding. The estimated incidence of asthma found in the welding cohort was about four times as high as that estimated for the United States general population by McWhorter et al. in 1989 (Ref. 171). While Wang et al. noted that their study suffered from loss of statistical power because of the relatively small number of cases, they concluded that the results suggest that both stainless steel and mild steel welding are associated with a relatively high incidence of asthma.

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. Reports include the diagnosis, age, sex, place of residence, occupation, and suspected causative agent (Ref. 175). Among the respiratory diseases reported in the 3-year period 1989–1991, silica was the

Table 4
Air Concentrations of Particles and Metals in the Breathing Zone During SMAW of Stainless Steel (SS), GMAW of Mild Steel (MS), and Assembly Work

Process (n = number of workers)	Particles mg/m^3	Total Chromium $\mu g/m^3$	Manganese $\mu g/m^3$	Nickel $\mu g/m^3$
SMAW-SS (n = 10)				
Median	2.4	82	61	26.2
IQ[a] Range	1.4–4.5	45–210	21–119	15.9–43.9
Maximum	15.4	351	169	72.3
GMAW-MS (n = 9)				
Median	6.7	<3.5	389	<3.3
IQ[a] Range	3.9–13.01	<3.5–4.5	114–1337	<3.3
Maximum	17.5	6.0	2319	68.8
Assembly (n = 10)				
Median	0.14	<1.4	<1.4	<1.4
IQ[a] Range	0.12–0.21	<1.4	<1.4	<1.4
Maximum	0.44	<1.4	6.	<1.4

a. Interquartile (IQ) range represents the middle 50% of the exposure distribution range (between the 25th and the 75th percentile).

Data from Wang et al., 1994 Ref. 276.

most frequently cited exposure in patients with pneumoconiosis, spray painting was the most frequently cited exposure in patients with occupational asthma, and welding fumes were the most frequently cited exposure in patients with occupational bronchitis. During this time, diseases related to asbestos exposure (malignant mesothelioma and nonmalignant pleural disease) were more frequently reported in engineers and foundry workers followed by shipyard and dock workers (Ref. 175). Meredith (Ref. 174) evaluated the new cases of asthma reported for all occupations during 1989 and 1990 according to workplace exposures. Occupational asthma represented 1085 of the 4229 (26%) cases of work-related respiratory disease reported to the SWORD project during this period (Ref. 174). The two exposures with the highest incidence of asthma were isocyanates (241 cases or 22.2% of the total number of occupational asthma cases) and soldering fumes (69 cases or 6.4%). 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. 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).

Contreras et al. (Ref. 47) conducted an epidemiological study of the occurrence of occupational respiratory diseases in British Columbia, Canada, in 1991, using a methodology of voluntary reporting by physicians similar to that developed for the SWORD project. Asthma was diagnosed in 124 of the 246 new cases of occupational lung disease reported in this survey in 1991. Wood dust, various chemicals, and isocyanates accounted for 102 (82%) of the cases. Welding fumes were the suspected cause of four (3.2%) cases of asthma.

Boulet et al. (Ref. 35) studied 11 patients (7 male and 4 female), aged 20 to 54, with occupational asthma. Welding was implicated as the etiologic agent in two of the cases. The patients and six normal controls were examined by bronchoscopy, bronchoalveolar lavage (BAL), and bronchial biopsies to determine the degree of inflammation in the lungs and by spirometry to determine the FEV_1. Baseline FEV_1 values were, on average, 93% of the predicted values among the patients. Minimal inflammatory changes were observed in the BAL fluid obtained from the patients. Although marked inflammatory changes were seen in the biopsy tissues, none of these differences were attributed to welding or to any other suspected causal agent.

Billings and Howard (Ref. 19) reviewed published studies of respiratory symptoms among welders. Three studies (Refs. 53, 121 and 195) which showed that the effects of smoking and welding exposure appeared to be additive and of about the same magnitude are summarized in Table 5. Billings and Howard concluded that the association of welding fumes with obstructive airways disease could be as important as that of smoking.

8.3 Reactive Airways Dysfunction Syndrome. Reactive airways dysfunction syndrome (RADS) is characterized by asthma and bronchial hyperreactivity. RADS resembles asthma in its effects, which include dyspnea, wheezing, and cough, but it differs from asthma in that it cannot be evoked by exposure to small doses of a

Table 5
Percentage of Men with Respiratory Symptoms

	Welders		Controls	
Authors	Smokers	Nonsmokers	Smokers	Nonsmokers
Hunnicutt et al.[a] (Ref. 121)	79	41	36	5
Oxhoj et al.[b] (Ref. 195)	34	23	16	6
Cotes et al.[c] (EWH8 Ref. 53)	45	25	26	15

a. Percent of men with one of the following: chronic cough, raising sputum, wheezing, dyspnea.
b. Percent of men with cough and expectoration.
c. Percent of men with chronic bronchitis.

Adapted from Billings and Howard, Ref. 19.

causative element and it is not associated with allergy. The bronchial hyperreactivity can persist for more than one year. Welding gases are among many agents which have been identified as possible causative factors for RADS (Ref. 197). Palczynski (Ref. 197) noted that patients are usually exposed to many diverse substances, making assignment of precise causes for RADS problematic.

8.4 Pneumonia. A striking excess of mortality from pneumonia was noted among welders in England and Wales between 1949 and 1953 (Ref. 213). To determine if the hazard of pneumonia in welders had persisted, Coggon et al. (Ref. 46) analyzed three more recent sets of occupational mortality data for England and Wales. Age-specific death rates from pneumonia among the general population and among metal-working occupations, including welding, were obtained for the periods 1959–1963, 1970–1972, and 1979–1990 from the British Registrar General's decennial supplements and the British census office. Standardized mortality ratios (SMRs), comparing age-adjusted mortality of welders with that of the general male population, and proportional mortality ratios (PMRs), adjusted for both age and socioeconomic class, were calculated using these data. The mortality from pneumonia was significantly increased in welders included in the 1959–1963 survey (SMR = 184, CI = 150–224) and the 1970–1972 (SMR = 157, CI = 121–200) survey. Retired welders (age 65 to 74) were included in the 1970–1972 survey and showed no excess mortality from pneumonia. Specific types of pneumonia were listed in the last survey (1979–1990). Welders aged 20 to 64 in this survey had significantly higher mortality from lobar pneumonia (PMR = 255, CI = 192–332) and "other and unspecified" pneumonia (PMR = 211, CI = 141–303). Three other groups of metal workers also had significantly increased mortality from lobar pneumonia. Retired welders in this group did not have excess pneumonia deaths. According to the authors, this last observation effectively rules out confounding by nonoccupational factors and points to a reversible effect of welding fumes on susceptibility to pneumonia. Thus, they stated that there are strong grounds for classifying lobar pneumonia as an occupational disease in welders.

In a response to Coggon et al. (Ref. 46), Kennedy (Ref. 143) disputed the specific identification of welders as a group at risk for lobar pneumonia and argued that the use of proportionate mortality ratios "is weak in its ability to identify specific risk factors and to control for extraneous confounders." Kennedy noted that the excess of pneumonia may have been the result of a combination of increased susceptibility and increased exposure potential in the metal trades, in general. She contended that there is "insufficient evidence to discriminate among the specific job titles in the metal trades," and that the generic job classification would be more prudent, since "exposures, not jobs" are the causes of occupational diseases. Kennedy concluded that Coggon's findings should be an incentive for other researchers to reexamine pneumonia as a potential occupational disease in the metal trades.

8.5 Pneumoconiosis. Pneumoconiosis is defined as the accumulation of nonliving particulate matter in the lungs, and the fibrotic tissue reaction to its presence. Not all dusts cause pneumoconiosis, and the severity of this condition varies with different types of dusts. When fibrogenic dusts, such as those containing silicates, are inhaled and deposited in respiratory tissue, pathological changes detectable by X-ray occur within the lungs. Localized reactions to particles in the alveoli lead to the formation of fibrous nodules which appear in early stages of pneumoconiosis as small discrete opacities. If excessive exposure continues, the opacities increase until adjacent lesions coalesce to form large opacities several centimeters in diameter, which may be indicative of serious lung damage (Ref. 179).

The incidence of occupational pneumoconiosis in Poland was examined during the years 1961 to 1992 by Marek and Starzynski (Ref. 165). Data on the prevalence of diseases were obtained from the Central Register of Occupational Diseases, and information concerning employment was obtained from the Chief Statistical Office. Approximately 17% of all occupational diseases reported in Poland during the study period were pneumoconioses. Over 92% of the cases occurred in workers 40 years of age or older and most affected workers had a history of at least 20 years of occupational exposure before developing the disease. The most prevalent diseases were coal workers' pneumoconiosis and silicosis, diagnosed in 5 and 2.8 of every 100 000 workers, respectively. The incidence of arc welders' pneumoconiosis was the next most prevalent form, and it appeared in 0.7 of every 100 000 workers. While the authors recognized that most cases of pneumoconiosis are related to long-term exposure to dusts, and, in general, reflect past exposures, they surmised that current work conditions were such that pneumoconiosis still presents a significant occupational health problem in Poland.

Shmuter et al. (Ref. 233) examined several parameters of the immune systems of 231 welders and foundry workers who were being treated for pneumonoconioses. Of the 105 patients with uncomplicated pneumoconiosis, 71 had silicosis and 34 had welders' pneumoconiosis. In the remaining patients, the pneumoconiosis was complicated by active tuberculosis in 71 cases and by inactive tuberculosis in 55 cases. Immune cell populations and immunoglobulin levels in blood were compared with

those from 52 age- and sex-matched healthy controls. Total and active lymphocytes were elevated among all the patients, as were the levels of immunoglobulin A (IgA). The only significant differences found between the welders with pneumonoconiosis and the silicosis patients were a greater percentage of theophylline- or histamine-sensitive T-lymphocytes and a higher level of IgA among the silicosis patients. The authors attributed these differences to the more extensive inflammatory processes in the lungs of silicosis patients.

None of the immune factors examined differed significantly between patients with inactive tuberculosis and patients with noncomplicated pneumonoconiosis. The numbers of lymphocytes and the concentrations of immunoglobulins were significantly greater in patients with active tuberculosis than in the pneumoconiosis patients who had no signs of tuberculosis. Thus, the authors surmised that the tuberculosis status was probably more responsible than the stage of pneumonoconiosis for the changes in immune status.

Savvaitova et al. (Ref. 227) followed 749 Russian patients with various types of pneumoconiosis for 3 to 25 years. Pneumonoconiosis was attributed to exposure to welding fumes in 112 of these patients. In 9.8% of the welders, the disease was complicated by tuberculosis (TB), and 14.2% of the welders had chronic bronchitis as well as pneumoconiosis. Annual follow-up examinations included chest X-ray, upper respiratory function testing, electrocardiogram, analysis of lung fluids, and a check for the tuberculosis bacterium. Welders with TB or chronic bronchitis were removed from welding work. Welders with interstitial and nodular pneumonoconioses were allowed to continue welding, but not in confined spaces. Welders were treated with medication to limit progression of the disease. Regression of the pneumonoconiosis occurred in 23.2% of the affected welders. The authors concluded that pneumoconiosis can be most effectively stabilized by a change of occupation and a regular treatment regime.

Siderosis is a type of pneumoconiosis caused by inhalation of iron oxide fumes produced by welding and other processes. Siderosis, which is readily apparent in chest X-rays, is often considered to be a benign condition, not associated with fibrotic processes. However, irreversible changes, such as fibrous thickening of the alveolar wall associated with iron deposits in the lung, have been reported. Persons with this condition may be symptomless or may experience coughing, reduced pulmonary function, and shortness of breath. Billings and Howard (Ref. 19) reviewed reports of siderosis and they concluded that disability due to the disease is modest, but that, "…radiological siderosis could be considered as a marker of serious welding fume exposure." Hasegawa and Sakamoto (Ref. 105) described a case of a symptomless 49-year-old man with extensive siderosis who had performed arc welding for 20 years. Abnormal shadows and massive foci of scar tissue were found in chest X-rays during a routine medical checkup. Rubin and Bruderman (Ref. 224) described a case of siderosis in a 39-year-old Israeli welder.

8.6 Asbestosis. As part of a clinical screening program, 600 asbestos-exposed individuals were examined, and some of them were referred to hospitals for further diagnostic evaluation. Klaas (Ref. 148) examined 75 of the patients who were referred to hospitals. These subjects had previously been employed as shipyard welders, riggers, pipe fitters, longshoremen, boilermakers, machinists, insulation strippers, janitors, and laborers, and had been exposed to asbestos for between 2 and 42 years, with a mean exposure of 22.7 years. They were evaluated for the presence of asbestosis by physical examination, pulmonary function tests, chest X-rays, high-resolution computed tomography (HRCT), gallium-67 scanning, and clinical laboratory tests. Sixteen of the patients met the clinical definition of asbestosis, which was considered confirmed when three of the following four criteria were met: reduced FVC; reduced diffusion capacity; bibasilar rales; and evidence of asbestosis on the chest X-ray.

HCRT, a technologically advanced technique that is more sensitive than X-ray in detecting morphologic abnormalities, showed positive findings for asbestosis in 59 of the patients, including 15 of the 16 clinically confirmed cases, and in an additional 44 subjects who had not met the established criteria for clinical asbestosis. Gallium scanning, which detects active inflammatory processes, was positive in 67 subjects, including 15 of the 16 who had clinically confirmed asbestosis and all of those who were found to be positive with HCRT. The author proposed that these two reliable, highly sensitive, non invasive techniques may represent an adequate basis for diagnosis of asbestosis in the absence of a demonstrable loss of lung function.

8.7 Analysis of Biopsied Lung Tissue Samples. Inhaled asbestos fibers can be retained in the lung for long periods of time. Many of the retained fibers become coated with iron-protein complexes by the action of alveolar macrophages to form drumstick-shaped asbestos bodies (ABs) which, when found in lung fluid or tissues, are often taken as indicators of asbestos exposure. Pairon et al. (Ref. 196) determined the AB content of 40 sputum samples, 147 BAL fluid samples, and 38 lung tissue samples taken from 211 French welders that had been submitted by physicians for analysis after a preliminary diagnosis of lung disease had been made. Smoking history, work history, and the preliminary medical diagnosis

were provided by the referring physician. The welders were grouped according to the preliminary medical diagnosis into potentially asbestos-related (e.g., specific types of fibrosis, lung cancer, and mesothelioma) and non-asbestos-related diseases (e.g., tuberculosis, pneumothorax, and pneumonia).

ABs were found in tissue and BAL samples from 82 of the 211 welders (39%). There was no relationship between the prevalence of ABs and the type of respiratory tract sample examined. Welders who had been employed in jobs considered to have had been associated with a high probability of exposure to asbestos (e.g., shipyard, power station, and heating plant workers) had a significantly greater number of ABs in lung tissue samples than did welders who had been employed in jobs considered to have a low probability of asbestos exposure. Duration of welding activity was significantly correlated with the AB content of BAL fluid and lung tissue. However, the prevalence of ABs was not higher in patients with asbestos-related disease than in patients whose diseases were not thought to be related to asbestos exposure. The authors suggested that errors in the initial diagnoses, especially for diseases requiring histological confirmation, may have led to this anomolous finding.

Raithel et al. (Ref. 211) analyzed and compared the chromium and nickel content in autopsied tissue samples from the lungs of 30 deceased persons (29 men and 1 woman) who had no history of occupational exposure to nickel or chromium with the chromium and nickel content in the lungs of ten deceased persons who had been involved in nickel refining or welding. In the exposed group, one had been a foundry worker, five had been nickel refinery workers, and two had been stainless steel welders in a nickel refinery. One was described as a flame-sprayer who had used welding powders containing 70–95% nickel, and the last had been a flame- and plasma-cutter. Half of these workers died from lung cancer. The lungs of nonexposed persons contained five to six times more chromium than nickel. The median metal concentrations in lung tissue from the nonexposed persons ranged from 20 to 40 ng nickel per gram lung tissue and from 133 to 277 ng chromium per gram lung tissue. The nickel concentrations in lung samples from nickel refinery workers exceeded the range in the non-exposed persons by about 1000 times but the chromium levels did not differ. Nickel levels were about 300 times higher than normal in lung tissue from the flame-sprayer. Both metals were elevated 10- to 70-fold in lung samples from the two stainless steel welders and from the flame cutter. The authors concluded that insoluble or very slightly soluble nickel and chromium compounds tend to accumulate in human lung tissue following inhalation exposure at the workplace.

9. Case Reports

9.1 Cadmium. Cadmium is a severe respiratory tract irritant. Inhalation of cadmium can cause pulmonary edema (accumulation of fluid in the lungs) within hours after exposure, followed by chemical pneumonitis. 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 filler metal containing cadmium. After brazing for 7 hours, he developed a high fever, chills, and shortness of breath. He went to the hospital where blood gas analysis indicated severe oxygen deficiency. A chest X-ray revealed a diffuse bilateral lung shadow, and a lung biopsy specimen showed lymphocyte infiltration and fibrous changes of the alveolar walls. He was diagnosed as having granulomatous pneumonitis. His symptoms and X-ray profile improved with steroid therapy.

Seidal et al. (Ref. 230) described the case of a 78-year-old man who developed chemical pneumonitis and respiratory insufficiency 3 hours after being in an enclosed room for 15 minutes where a friend was brazing stainless steel with a silver brazing rod containing 20–30% cadmium. While the friend wore respiratory protection and suffered little effect from exposure, the patient had worn no respiratory protection. After 3 days, he was hospitalized and treated with oxygen and bronchodilators, but his condition continued to deteriorate and he developed severe chemical pneumonitis. He died from respiratory insufficiency 25 days after exposure. Extensive pulmonary fibrosis was found at autopsy. Blood samples taken at autopsy contained 530 nmol cadmium/L, indicating significant exposure. The authors speculated that the outcome of this case might not have resulted in death had cadmium exposure been recognized immediately and the patient treated with steroid therapy.

9.2 Lead. Ziegenfuss et al. (Ref. 287) reported an incident in which a man was hospitalized after oxyacetylene welding lead-coated iron plates. He welded for most of the day in an enclosed room. That evening he became ill, with coughing, nausea, and difficulty breathing. He was treated with steroids and recovered almost completely within 3 weeks.

9.3 Zinc. A case of a smelter with hypersensitivity pneumonitis, apparently induced by exposure to zinc oxide fumes, was described by Ameille et al. (Ref. 5). This 35-year-old man had been working in a nonferrous metal foundry for 3 years when, on two separate occasions, he became ill with shortness of breath, fever, and cough. While his symptoms were similar to metal fume fever, they took 3 to 7 days to resolve. Examination showed a moderate change in pulmonary function, with an increased lymphocyte count in the BAL fluid. All signs of

discomfort ceased shortly after he stopped working at the foundry. A month later, he developed classic signs of metal fume fever (fever, cough, shortness of breath) several hours after welding galvanized metals at home. The symptoms lasted for 5 days. This case was distinguishable from metal fume fever by the severity and duration of symptoms, late emergence (he was exposed for 3 years before reacting to zinc), significant and long-lasting changes in pulmonary function, and lack of tolerance to zinc oxide. The authors concluded that the man had developed a hypersensitivity to zinc, and cited two other published examples in which zinc appeared to act as a sensitizing agent.

Glass et al. (Ref. 91) described a case of chronic interstitial lung disease in a 32-year-old welder who received an intense exposure to fumes generated by welding galvanized steel. His career as a welder began at the age of 17 when he used SMAW to repair mild steel farm machinery. Between the ages of 21 to 28, and then again at age 32, he welded galvanized steel mesh onto galvanized steel frames using GMAW with argon as the shielding gas during the manufacture of sheep and cattle crates. The welding was conducted in an area so poorly ventilated that the room "filled with smoke." The man experienced shortness of breath when lifting heavy objects 3 months after returning to the job at age 32. This exertional dyspnea continued to worsen and eventually was accompanied by chest pain. After a year and a half, his symptoms forced him to give up welding. His condition was diagnosed as a restrictive lung disease with severe reduction in diffusing capacity. The physicians related his disease solely to his welding experience, but it is also possible that his employment between the ages of 28 and 32 repairing and spray painting fiberglass boats may have contributed to his condition.

9.4 Asbestos. The case of a shipyard welder who died of mesothelioma was described by Levin (Ref. 159). This condition, which is almost always associated with exposure to airborne asbestos, was largely attributed to his welding experience in a shipyard during World War II. Levin noted that he also had worked as a laundromat operator from 1966 to 1981. Part of that job required frequent disassembly and sanding of the washing machine clutch linings which contained 10 to 12% chrysotile asbestos. The manufacturer confirmed that chrysotile was used in the clutch linings until 1980. This case report clearly demonstrates the necessity for conducting a complete occupational history before attributing a disease condition to any single occupational exposure.

9.5 Hard Metal. Hard metal is a mixture of tungsten carbide with cobalt powder which is used as a surface coating for cutting and polishing tools. Chronic exposure to aerosols of this mixture can cause occupational asthma and a progressive form of interstitial pulmonary fibrosis, with a characteristic lung pathology. The latter occurs infrequently among exposed workers and does not appear to be related to the severity of exposure, which suggests that individual susceptibility may vary widely. In some individuals, a severe and rapidly progressive interstitial fibrosis may lead to early death. Hard metal disease is usually attributed to the cobalt component of the tungsten carbide-cobalt mixture. Metal analysis of biopsied or autopsied tissue from patients with hard metal pulmonary disease frequently shows tungsten carbide and cobalt, or tungsten carbide alone, presumably reflecting the greater solubility and shorter half-life of cobalt in the lung.

Figueroa et al. (Ref. 72) described two cases of hard metal pulmonary interstitial fibrosis in men exposed to fine, aerosolized, hard metal dust at a plant where hard metal coatings were applied to premanufactured metal parts using the detonation gun process. This process uses high heat and pressure to weld the hard metal coating onto metal surfaces. The first case involved a 48-year-old male who was employed for 23 years both as a grinder of coated metal parts and in the metal parts coating operation. During the last 10 years of his employment, he worked in management and had little dust exposure. He was admitted to the hospital following a 3-year history of cough and dyspnea. His occupational history, chest X-ray, and lung biopsy indicated hard metal pulmonary disease; metal analysis of lung tissue was not conducted. He died 4 years later with severe parenchymal lung disease.

In the second case, a 35-year-old male who worked in the metal parts coating operation developed frequent cough and dyspnea after 3 years of employment. After 8 years, his condition became chronic and progressive and was suspected to be hard metal pulmonary disease. Examination of biopsied lung tissue by energy dispersive X-ray analysis revealed particulate material containing iron, potassium, calcium, and zinc with lesser concentrations of silicon, aluminum, and tin; neither cobalt nor tungsten was identified. During the entire time he worked with the hard metal coating process, effective ventilation was in place and industrial hygiene measurements never revealed cobalt levels above the OSHA PEL of 100 $\mu g/m^3$. It should be noted that for an unspecified period of time before the age of 27, this man had worked as a machine operator performing drilling, grinding, and boring in an aircraft engine reconditioning plant. In addition to this experience, the inability to identify cobalt and tungsten in lung biopsy material, makes the diagnosis of hard metal disease questionable. The author concluded that, "The fact that two cases of hard metal pulmonary interstitial disease occurred where thorough exposure control procedures and a surveillance program for cobalt were in place may indicate the need for revisions of the

current technology used when hard metal is applied in the detonation gun process."

10. Cancer

10.1 Lung Cancer. In 1984, a commission of the International Institute of Welding concluded that there were insufficient data to draw conclusions about the risk of cancer among welders (Ref. 290). The commission subsequently revised its position, based upon the accumulation of evidence since 1984. In 1993, it concluded there is, "…sufficient evidence that welders as a group have a slightly greater risk of developing lung cancer than the general population," and, although the contribution of smoking and asbestos exposure is unknown, it probably does not account for all of the elevated risk. The commission also concluded that neither the responsible welding processes nor specific components of welding exposures which may contribute to an excess risk for cancer have been identified, although nickel and chromium compounds arising from processes other than welding have been shown to be carcinogenic. Some of the recommendations of the commission were: (1) identify constituents of welding fume; (2) reduce nickel and chromium exposures to levels equal to or less than established workplace exposure standards; (3) prevent asbestos exposures; and (4) monitor exposures.

In 1990, the International Agency for Research on Cancer (IARC) evaluated 23 epidemiology studies of the incidence of cancer in welders (Ref. 124) and concluded that welding fumes are possibly carcinogenic to humans, based on limited evidence in humans and inadequate evidence in experimental animals. The studies that IARC considered in arriving at this conclusion were reviewed in *Effects of Welding on Health, Volume IX*. The epidemiologic evidence for lung cancer among welders was bolstered by the results of a nine-nation historical European cohort study (Ref. 234) which pooled data from 21 case-control and 27 cohort studies of 11 092 male welders. Analysis of the combined data from these studies showed a significantly greater mortality rate from lung cancer among male welders than among men in the general population from the same countries. The SMR (expressed as a percentage) for lung cancer among welders compared with non-welders in the same countries was 134. The 95% confidence interval (CI)[1] was 110–160. Five deaths from mesothelioma, which is almost always associated with asbestos exposure, occurred in the population of welders studied, implicating asbestos exposure as a confounding factor. Estimated cumulative doses of fume, total chromium or Cr(VI) from welding of stainless steel were not significantly associated with mortality from lung cancer.

Moulin et al. (Ref. 183 and 184) continued the French portion of the nine-nation lung cancer mortality study (Ref. 182 and 234). They added additional years to the follow-up data in the five French factories included in the original study and added eight new shipyards and factories. Data were collected from 2721 welders and 6683 controls, and an effort was made to control for smoking habits. Stainless steel welding activities had generally commenced in these factories in the decade 1950–60. The 12-year follow-up period began in 1975 to allow for at least a 10-year lag time in the development of cancer. The control population was drawn from non-welders in the same factories who also had never worked in foundries or as painters, boilermakers, or cutters. Except in factories with insufficient numbers of non-welders, three controls were randomly chosen for each welder. There were 730 deaths in the whole study population, determined from factory records, registry offices, and national files. Smoking habits were obtained from records of annual physical examinations.

SMAW was the predominant welding technique used in most of the factories. Exposure histories were available on an individual basis in eight of the factories and were estimated from workshop records in the other five. The welders were classified into four groups according to the length and intensity of their experience welding stainless steel. Standardized mortality ratios were determined by comparison with French national death rates. The SMR for all cancers combined was close to 100 for both welders and controls, showing no difference between the incidence of cancer among the subjects and the general population. A statistically nonsignificant increase in the relative risk (RR = 1.32) for lung cancer among welders was observed. Death rates from malignant or nonmalignant lung disease were not significantly different among stainless steel welders compared with other welders. There was a significant increase in ischemic heart disease in each of the groups of welders, but the authors noted that this finding has not been reported in other studies and could be due to chance. A significant increase in lung cancer mortality was found among mild steel welders exposed for 20 or more years

1. The CI refers to the range of values in which the true value of a statistic would be found with the stated level of confidence 95% if not otherwise noted. Thus, since an SMR of 100 would represent no difference in lung cancer mortality between welders and the test population, the CI shows that there is a 95% certainty that there was at least a 10% greater incidence of lung cancer among welders and that the extent of the increase was no more than 60%.

(SMR = 324, CI = 105–755) and for those with at least 20 years since the first exposure (SMR = 242, CI = 105–478). These were the only exposure groups with significantly elevated mortality from lung cancer in the study by Moulin et al. (Ref. 183). However, when the data developed by Moulin et al. (Ref. 183) were analyzed by Sjogren (Ref. 239) in combination with data from four other studies (Refs. 89, 101, 147 and 237), a statistically significant relationship was found between stainless steel welding and lung cancer mortality.

Danielsen et al. (Ref. 58) determined the cancer incidence among male workers first employed at a Norwegian shipyard between 1940 and 1979. In this historical cohort, 625 workers were identified as welders, and 3325 workers formed an internal reference group composed of men who had never been employed as welders. The study subjects were followed from 1953 to 1990. SMAW had been introduced to the shipyard around 1940, followed by GMAW and GTAW in the 1970s. Mild steel was the main metal welded until 1976. Stainless steel was introduced in 1977, and by 1990 about 50% of the metal welded was stainless steel. Asbestos had been used for insulation until the early 1970s, and exposure to asbestos continued after that time due to its removal during ship repair. There was insufficient information to control for smoking in this study, but a 1984 survey in this shipyard showed a 10–20% higher prevalence of daily smoking among welders and other shipyard workers than in the Norwegian male population with which the shipyard population was compared.

Standardized incidence ratios (SIRs) were calculated by dividing the numbers of cancers observed in the welder and reference groups by the number expected based on age-adjusted data from the Cancer Registry of Norway. In the whole cohort of shipyard workers, the incidence ratios for all cancers (SIR = 1.13, CI = 1.02–1.26) and for lung cancer (SIR = 1.40, CI = 1.08–1.79) were significantly elevated. Lung cancer among welders was also significantly higher than in the Norwegian male population (SIR = 2.50, CI = 1.14–4.75). Excluding cancers diagnosed in the first 15 years of employment at the shipyard (to account for a lag time in the development of cancer) produced greater SIRs for lung cancer in the entire cohort (SIR = 1.50, CI = 1.13–1.95), among all the welders (SIR = 3.08, CI = 1.35–6.08), and among those employed as welders for longer than 3 years (SIR = 3.75, CI = 1.38–8.19), or for more than 5 years (SIR = 4.00, CI = 1.10–10.20). No pleural mesotheliomas were seen among the welders (0.1 expected), but there were 4 cases in the never-welded population at the shipyard (0.9 expected: SIR = 4.44, CI = 1.22–11.33). This higher-than-expected incidence of mesothelioma was taken by the authors as evidence that the entire shipyard population, including the welders, had been exposed to asbestos. The incidence of skin cancer was also elevated in welders (SIR = 5.00, CI = 1.00–14.66), which the investigators suggested could be attributed to exposure to UV radiation from the welding process. Danielson et al. concluded that, "…there is a group of highly exposed welders of mild steel with excess risk of lung cancer even when accounting for smoking and asbestos as possible confounders." The greater incidence of smoking in the shipyard workers compared with the reference population could account for an SIR for lung cancer of about 1.25. However, the contribution of smoking could not account for the entire excess incidence among the shipyard population or for the increased incidence of lung cancer observed among the more highly exposed welders of mild steel. Because of the 10 to 20 year lagtime between first exposure to most carcinogens and the development of cancer, any contribution of stainless steel welding (introduced in 1977) to the development of lung cancer would not have been apparent at the end point of this study.

In a study of mortality among male automobile workers in Cleveland, Park et al. (Ref. 202) found that welders working in an automotive stamping plant had an elevated risk of death from lung cancer compared with workers in two assembly plants (OR = 2.7, CI = 1.2–6.3). The association between lung cancer and welding was strengthened when duration of welding experience in the stamping plant and prior welding experience were considered. However, the lung cancer mortality rates among workers in the assembly plants and the stamping plant were not significantly different from that in the general population. Welding in the assembly plant was performed, principally by resistance welding and occasionally arc welding, on sheet metal that was usually coated with drawing compound and often with primer or epoxy resin adhesive. The study population was drawn from records of deaths among the 16 197 hourly employees who had worked in the stamping and assembly plants for two or more years prior to 1989. Work history records were available for 141 of the 146 stamping plant workers and 253 of the 316 assembly plant workers who had died between 1978 and 1988. Their causes of death were determined from insurance data and death registries. There was a strong healthy worker effect, as shown by the overall mortality rate for both white men (SMR = 65) and black men (SMR = 79).

Using the New Zealand Cancer Registry, Firth et al. (Ref. 73) analyzed cancer deaths that occurred between 1973 and 1986 among male workers in New Zealand. A significant excess of lung cancer deaths occurred among welders compared with the New Zealand population of working men, adjusted for age and social class (SMR = 140, 95% CI = 120–161). An increased incidence of stomach cancer was also reported among welders (SMR

= 155), but neither the confidence interval nor the significance was reported for this finding.

Merlo et al. (Ref. 176) conducted a retrospective cohort study of cancer among 3890 male workers employed between 1960 and 1988 in an Italian shipyard. Occupational groups were not treated separately in this study. Mortality from all cancers combined was significantly elevated (SMR = 123, CI = 113–133) as was that for respiratory tract diseases (SMR = 123, CI = 106–141). Among site-specific cancers, mortality was significantly higher for lung cancer (SMR = 148, CI = 129–169) and pleural mesothelioma (SMR = 442, CI = 324–590). Occupational exposures encountered in the shipyard included asbestos, silica dust, welding fumes and gases, solvents and paint removers. After about 1970, exposure conditions improved, and age-adjusted SMRs for lung cancer and mesotheliomas decreased among the more recently employed workers. The authors stated that the excess in lung cancer mortality found among the shipyard workers was greater than could be accounted for by smoking.

Anttila et al. (Ref. 11) reviewed the occupations of the 17 118 workers who were entered into the Finnish cancer registry in 1989. Welders accounted for 14% of the reported cases, second only to engine repair workers (17%) among the identified occupations.

Jockel et al. (Ref. 134) reported interim results from a case-control study designed to examine the hypothesis advanced by other investigators (Refs. 15, 234, and 245) that findings of excess lung cancer in welders may have been confounded by asbestos exposure. When complete, the study will be comprised of 1000 lung cancer cases. The interim study was comprised of 391 newly diagnosed primary lung cancer patients recruited from three German hospitals. The 391 controls, matched by age, sex, and area of residence, were drawn from the general population. Cases and controls were interviewed to obtain smoking, dietary, residence, occupational, and medical histories. Quantitative estimates of asbestos exposure were derived from answers to job-specific questionnaires (Ref. 135). For welders, the questionnaire requested information about the type of welding procedure used, the metals worked with, welding of coated metals, working conditions, and duration and frequency of welding activity.

Odds ratios were calculated for each of four welding-exposure categories and adjusted for smoking and asbestos exposure. Among the lung cancer cases, 28% had welded for more than one-half year, compared with 22% of the controls. The unadjusted OR for welding was 1.35, and was significant; but, when adjusted for smoking and asbestos exposure, it was reduced and was not statistically significant (OR = 1.24, CI = 0.83–1.86). Neither welding in general nor oxyacetylene welding and SMAW was significantly related to excess lung cancer. After adjustment for smoking, lifetime exposure to asbestos of more than 4100 hours was present in a significantly elevated number of cases (OR = 1.88, CI = 1.11–3.19). Workers employed in the aircraft industry showed a significantly elevated OR of 2.14 after adjustment for smoking and asbestos exposure. The widespread use of beryllium in this industry suggested to the authors that beryllium-containing alloys may contribute to the incidence of lung cancer among these workers. The unadjusted OR of 1.35 for lung cancer among welders was consistent with findings in other studies, and the relative contribution of asbestos was also consistent with the finding by Ronco et al. (Ref. 218) that the estimated risk was reduced by 18% after adjustment for smoking and asbestos exposure. Jockel et al. concluded that some, but not all, of the excess risk for lung cancer among welders may be due to exposure to asbestos.

Keller and Howe (Ref. 142) conducted a series of case-control studies among male construction workers, using subjects from the Illinois State Cancer Registry. Of the 4987 cases of construction workers diagnosed with cancer between 1986 and 1989, 402 occurred in welders. Welding was one of several occupations within the construction industry that were selected and evaluated for the incidence of cancer in various organs. The controls for each type of cancer were randomly selected from the other cancer cases. Welding was associated with significant elevations in risk for stomach cancer (OR = 2.11, CI = 1.09–4.09) and lung cancer (OR = 1.68, CI = 1.03–2.76). The only other significant finding in the study was an increase in lung cancer associated with employment in the construction industry (OR = 1.18). No correction was made to adjust for tobacco use among the construction workers. According to Keller and Howe, “If the differences between cancer rates in construction workers and the general population were entirely attributable to tobacco use, positive associations with bladder cancer [which has also been associated with smoking] would be expected.” Instead, employment in the construction industry had a marginally negative effect upon bladder cancer in their study.

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. 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. Women aged 29 to 70 who were diagnosed with primary lung cancer between 1985 and 1987 in Shenyang and Harbin, China, were compared with an equal number of women randomly selected from the populations of the two cities and matched by age to the cases. There were a large number

of lifetime nonsmokers among the cases (43%) and the controls (63%). Statistically significant excess risks for lung cancer were found among workers in the occupational category of metal smelting and treatment. Excess risks were also found among welders, but these were not statistically significant. No correlation was found between duration of exposure and lung cancer among the welders or any other classification of workers in the study. Even in this study, the number of women in the welding population was not large enough to develop statistically significant relationships, but the authors concluded that there is a need to include women in future research on the role of workplace exposures in the development of lung cancer.

Some investigators have reanalyzed existing data to try to eliminate confounding by asbestos and smoking. Sjogren (Ref. 239) performed a "meta-analysis" of data from eight studies reported between 1984 and 1993 of lung cancer among welders of stainless steel. Only five of these studies had controlled for smoking and asbestos exposure (Refs. 89, 101, 147, 183 and 237). Three studies (Refs. 15, 120 and 234) did not adequately control for these confounding exposures and were excluded from the analysis. When only the five studies with appropriate controls were considered, a significant relative risk for lung cancer was found among welders of stainless steel (RR = 1.94, CI = 1.28–2.93). "This clearly indicates a relation between stainless steel welding fumes and the occurrence of lung cancer, when the two most important confounders, namely smoking habits and asbestos exposure have been taken into account (Ref. 239)."

Langard (Ref. 155) reviewed the epidemiological literature on populations of workers exposed to chromium and the evidence for its carcinogenicity in humans. Included in his analysis of chromium-exposed workers were two studies of lung cancer risk among welders of stainless steel (Refs. 234 and 237). While these studies showed a risk for lung cancer that was greater in stainless steel welders than in the general population, the risk did not approach that found in studies of chromate workers. Langard interpreted the data of Simonato et al. (Ref. 234) as indicating that stainless steel welders are more likely to die from lung cancer than are welders as a whole.

Marini et al. (Ref. 165) disagreed with Langard's interpretation of the data of Simonato et al. (Ref. 234), and argued that mild steel welders in the study were more at risk for lung cancer than were the stainless steel welders. These authors attributed the greater incidence of lung cancer in the welding population as a whole to smoking and asbestos exposure. Langard (Ref. 158) agreed that the evidence linking exposure to Cr(VI) to lung cancer in stainless steel welders is weak, but he cited recent papers (Refs. 249 and 250) which documented exposure to high levels of Cr(VI) among stainless steel welders using SMAW. He stressed the need for a large case-control study of lung cancer in men which would compile, "accurate and (semi)quantifiable information on past exposure to all known cancer determinants," and suggested an expanded follow-up study of the cohort that contributed to the Simonato study (Ref. 234).

Langard (Ref. 157) also reviewed recent studies of work-related lung cancer. He used statistical methods to partition the number of cases when there was exposure to several known causes of cancer and estimated the potential number of lung cancers among Norwegian workers in 1994 that could be attributed to various workplace exposures. Out of 1100 annual new cases among Norwegian males, 125 to 175 were attributable to asbestos. In contrast, fewer than 2 cases annually could be attributed to stainless steel welding, based largely on the data presented by Simonato et al. (Ref. 234). An additional 3 to 4 annual cases were attributable to exposure to chromium compounds presumably from sources other than welding.

Another review by Langard (Ref. 156) examined the studies of lung cancer among welders exposed to nickel and Cr(VI) conducted by Becker et al., (Ref. 16), Simonato (Ref. 234), and Sjogren (Ref. 237). Langard did not perform a mathematical analysis of relative cancer mortality, but he concluded that "there is evidence that exposure to welding fumes from [stainless steel] welding constitutes a slightly higher cancer hazard…than does [mild steel]-welding with the same techniques," but he found no conclusive evidence establishing as the prime cause for excess lung cancers among welders any of the suspected agents, including Cr(VI) or Ni and, "the toxic gases, some of which may generate free radicals."

Becker and Rittgen (Ref. 17) applied a mathematical model to data from a previously published epidemiologic study (Ref. 15) which had shown a significant excess of deaths from lung cancer among welders of stainless steel when compared with machinists in the same plants (RR = 1.6), but had failed to show a significant link between cancer mortality and duration of exposure to welding fumes. The mathematical model also did not predict an increased effect with increased cumulative exposure. Becker and Rittgen suggested that this inability to demonstrate a relationship between the duration of exposure and the cancer incidence, also seen in other epidemiological studies, may be an artifact of the way relative risks are calculated.

Kromhout et al. (Ref. 153) used data from a Dutch study to evaluate the performance of two general job-exposure matrices developed by Hoar et al., (Ref. 116) and Pannett et al. (Ref. 200) as compared with actual exposure data, in predicting lung cancer morbidity. The Dutch study had been performed in an industrial town in the Netherlands between 1960 and 1985 (Ref. 144). The subjects consisted of a random sample of men born

between 1900 and 1919 who had lived in the Dutch town of Zutphen for at least 5 years. Medical examinations and self-administered questionnaires concerning health status had been conducted several times during the 25 years of the study. In 1977 and 1978, information about job and exposure history was obtained from surviving members of this cohort by interview and questionnaire. These data were available for 856 men from the original study population of 878 who had been given medical examinations in 1960. Kromhout et al. (Ref. 153) constructed a matrix based upon the occupational exposures reported by the study participants, using the total 25 years of follow-up data in the study. This job exposure matrix showed a significantly elevated risk for lung cancer among welders (hazard ratio = 1.93; CI = 1.05–3.55). The generalized job exposure matrices, which estimated severity of exposure to welding fumes and several other industrial pollutants on the basis of reported occupation, without reference to individual exposure histories (Refs. 116 and 200) did not show a significant elevation in lung cancer among those identified as being exposed to welding fumes. Thus, in this study, estimation of exposure from job titles was found to be an inadequate substitute for gathering exposure histories by directly questioning study subjects.

Gerin et al. (Ref. 88) developed an exposure matrix to estimate the exposure of welders to nickel (Ni) and Cr(VI) in various welding processes (Table 6). The estimated 8-hour TWA concentrations were derived from the industrial hygiene literature (Refs. 163, 265 and 268–270), from literature provided by manufacturers of welding products, and from some industrial hygiene measurements taken in the mid-1970s in eight of the 135 companies that participated in the nine-nation European study (Ref. 234). This matrix was used along with individual exposure histories when these were available or, by default, with company history data to provide an estimate of the exposure history of each welder in the nine-nation European study (Ref. 234). When the matrix was used to calculate individual cumulative exposures to Cr(VI) and Ni and applied to the lung cancer mortality data, no dose-response relationship was found between mortality from lung cancer and any of the welding fume components evaluated, even among stainless steel welders who had been exposed to the known carcinogens Cr(VI) and Ni.

10.2 Thoriated Electrodes. Tungsten electrodes containing 1% to 4% thorium in the form of thoria (ThO_2) are widely used in GTAW to make the arc easier to start and more stable (Ref. 273). All isotopes of thorium are radioactive, and the intermediate, short-lived radionuclides in their decay chains also emit alpha- or beta/gamma-radiation, making the determination of radiation

Table 6
Welding Process Exposure Matrix
Estimated Exposure Levels (µg/m³) for Welding Processes and Base Metals

Process	Metal[a]	Total Fume	Total Chromium	Chromium (VI)	Nickel
SMAW	MS	6000	5	5	5
	SS	3000	150	120	30
GMAW	MS	6000	5	0	5
	SS	3000	300	9	150
	Al	9000	0	0	0
GTAW	SS	1000	10	5	10
	Al	1000	0	0	0
	MS	1000	0	0	0
Cutting	MS	9000	10	10	10
Oxyfuel gas welding	MS	3000	5	5	5
	SS	3000	150	100	30
Resistance welding	SS	1000	10	5	10
Plasma cutting	SS	6000	600	20	100

a. MS = mild steel; SS = stainless steel; Al = aluminum

Adapted from Gerin et al., Ref. 88.

dose from a thorium preparation complex. Prior to using them, the welder grinds the thorium electrode to a fine tip using a grinding wheel, an operation that usually takes 30 to 90 seconds (Ref. 56). Vinzents et al. (Ref. 273) calculated the lung cancer risk from grinding and welding with thoriated electrodes. Total and respirable dust were measured in the breathing zone of a worker wearing a protective mask during grinding of electrodes containing 4% thorium. The authors also calculated the rate of vaporization of a tungsten electrode containing 4% thorium and used a standard lung model (Ref. 125) to estimate the radiation dose to the lungs of a welder grinding and welding with thoriated electrodes during a 30-year working lifetime. Based upon cancer risk factors for the thorium isotopes published by the International Commission on Radiation Protection (Ref. 126), the worst-case estimate was that, "…in a group of 1200 workers, the number of excess cancers resulting from 30 years of GTAW, could probably be from zero to 3 cases." Vinzents et al. concluded that, although the excess cancer risk from thoriated electrodes is low, it is unnecessary. They recommended that thorium be replaced with a less-toxic alloying material such as lanthanum or cesium.

Crim and Bradley (Refs. 55 and 56) also measured air concentrations of thorium during grinding operations with two different types of grinders. Area and personal breathing zone samples were collected while the welder ground four thoriated electrodes in six minutes at each grinder. The radioactivity, measured in dissociations per second, or becquerel (Bq), by the area monitors ranged from 0.001 to 0.01 Bq/m^3 for a belt grinder to 0.056 to 0.3 Bq/m^3 for a ball-bearing grinder. Thorium activity was detected in one of the total particulate breathing zone samples (0.07 Bq/m^3). Activity above 0.01 Bq/m^3 was never detected in the respirable fraction. The Nuclear Regulatory Commission standard for thorium is 0.04 Bq/m^3. The authors noted that welders normally grind one electrode at a time instead of the four that were ground in their test, so that the excessive thorium activity in this sample may not be representative of conditions in the normal workplace.

McElearney and Irvine (Ref. 170) studied thorium exposure in welders employed by a British airline. In a preliminary investigation the authors determined that up to 63 Bq could be released when the welder ground 10 thoriated electrodes per day. The respirable fraction of the dust from grinding electrodes was estimated to be between 1 and 3%. The study population consisted of 64 GTAW welders, 11 other welders, and 61 controls, drawn from a similarly skilled labor group of airline employees. All participants were male. Smoking habits and alcohol consumption were similar in welders and controls. Occupational histories provided by the welders included the frequency of tip grinding. Respiratory symptoms were more prevalent among the welders than among the controls, but not significantly so, and no other differences in morbidity or medical events were apparent in the three groups of participants. Chest X-rays were taken of all participants. Five minor lung abnormalities were found among the GTAW welders, compared with none in the controls and non-GTAW welders. The investigators found no evidence that suggested a link between the lung abnormalities and thorium exposure.

Blood and urine samples were taken from all participants and were analyzed for components indicative of liver and kidney function. There were no differences among the three groups in any of the measures of kidney function. The only significant finding was a lower level of blood aspartate aminotransferase (AST), a serum indicator of liver function, in the GTAW welders than in the controls. This result was opposite to that found in a previous study of thorium refinery workers, who had significantly elevated AST levels (Ref. 68). The urine from the welders and eight of the controls was also analyzed for the two major isotopes of thorium. Thorium was below the detection level in most of the samples. When thorium was detected, neither its presence nor its concentration could be related to years of welding with thoriated electrodes. The estimated maximum dose of thorium to the GTAW welders was never in excess of the standard of the International Commission on Radiological Protection. The authors, nevertheless, recommended the following precautions: the thoriated electrodes should be stored in metal containers, never on the person of the welder; the grinding wheel should be dedicated to the grinding of electrodes, it should be ventilated, and it should be cleaned at the end of each work day; accumulated dust and spent electrodes should be disposed of in accordance with local regulations concerned with radioactive waste.

10.3 Extraneous Exposures. Verma et al. (Ref. 272) conducted an industrial hygiene survey to evaluate a Canadian study (Ref. 216) that had found that lead welders in one nickel-copper smelter and refinery had a greatly increased rate of death from lung cancer (SMR = 891), while lead welders in another such plant, who had similar exposures to lead, arsenic, copper, nickel, and asbestos, did not show any excess lung cancer risk. The investigators found that welders in the first plant spent more than 60% of their time in areas where they would have been exposed to polycyclic aromatic hydrocarbons (PAHs) from constant floor-repair operations, whereas the workers in the second plant were not exposed to measurable levels of PAHs. Verma et al. concluded that the high lung cancer risk among lead welders in the first plant was most likely to have been related to their exposure to PAHs, and that the effect of the PAHs may have

been enhanced by the particulate matter and irritant gases that were also present in the environment.

10.4 Naso-Pharyngeal Cancer. Holt (Ref. 118) reviewed recent literature on the relationship between sinonasal neoplasms and exposures to industrial air pollutants. He cited occupational exposure to wood dust, cadmium and chromates, formaldehyde, mineral oils, glues, solvents, paints, and by-products of textile manufacture as suspected causes of sinonasal cancer. He identified welding, mining, oil and gas work, construction, and cotton picking as occupations possibly associated with an elevated risk for sinonasal cancer. He recommended that prospective studies should be conducted to investigate the "natural history" of sinonasal neoplasms.

Zheng et al. (Ref. 285) examined the relationship between occupation and the incidence of naso-pharyngeal cancer in Shanghai, China. Occupation at the time of cancer diagnosis was obtained from interviews with the patient or next-of-kin for the 996 patients diagnosed with naso-pharyngeal cancer between 1980 and 1984. Incidence rates were calculated by comparing the number of cases of naso-pharyngeal cancer in the various occupational classifications with the 1982 occupational census for Shanghai. These in turn were compared with age- and sex-related and site-specific cancer-incidence data in the Shanghai Cancer Registry. Male patternmakers and cutters had a significantly increased incidence of naso-pharyngeal cancer (SIR = 280). While brief mention is made of welders, no statistics or data are presented and conclusions concerning the incidence of naso-pharyngeal cancer in welders cannot be drawn from this work.

Luce et al. (Ref. 162) conducted a case-control study of sinonasal cancer in France. Cases were diagnosed between 1986 and 1989 with primary malignancies of the nasal cavity and sinuses. Detailed information on job history and other potential risk factors for sinonasal cancer were obtained for the 207 cases and 409 controls by interviews using a questionnaire designed to assess exposures to formaldehyde and other substances (i.e., wood dust, leather dust, textile dust, flour dust, sugar dust, coal/coke dust, nickel compounds, chromium compounds, Cr(VI), welding fumes, soldering fumes, cutting oils, paints and lacquers, and glues and adhesives). The risk for sinonasal squamous cell carcinoma was significantly associated with exposure to medium-to-high levels of flour dust. In addition, a strong association between adenocarcinoma and medium-to-high exposure to wood dust was found. The risk associated with exposure to wood dust increased more than five-fold when combined with exposure to formaldehyde. "Probable or definite" exposures to welding fumes, total chromium, or Cr(VI) were not associated with an increased risk for sinonasal cancer.

10.5 Bladder Cancer. In the nine-nation historical European cohort study (Simonato, 1991) bladder cancer was found to be significantly elevated among welders, but no correlation was found between development of this disease and the duration of exposure or time since first exposure to welding. In their study of construction workers, Keller and Howe (Ref. 142) reported that employment in the construction industry was marginally associated with a decreased risk for bladder cancer.

Goldstein and Brandt-Rauf (Ref. 92) reviewed the epidemiological literature concerned with occupationally related bladder cancer and listed welders among the scores of occupational groups associated with an increased risk for the disease. While the specific causative agents have not been identified, they noted that cigarette smoking was considered to be, "probably the largest single attributable risk for development of bladder cancer."

Cordier et al. (Ref. 48) conducted a case-control study which assessed the relationships between occupational risk factors and bladder cancer in France between 1984 and 1987. Cases (658 men and 107 women) were compared with controls matched for sex, age, ethnic origin, and place of residence. A significant excess of cases was found among male welders compared with controls (unadjusted OR = 8.05). However, when the OR was adjusted for smoking status, hospital, age, and place of residence, it was reduced (OR = 7.00, CI = 0.87–56.62) and became nonsignificant.

Zaridze et al. (Ref. 284) conducted a case-control study relating bladder cancer to industrial occupations in the former Soviet Union. A nonsignificant increase in the relative risk for bladder cancer was found among welders (RR = 1.5, CI = 0.48–4.67). Smoking was highly correlated with bladder cancer (RR = 4.5, CI = 1.80–9.84). Examination of dietary habits of patients and controls indicated that the risk for bladder cancer was significantly reduced among those whose diets were high in beta-carotene and vitamin C and among those who cooked with vegetable oil or margarine rather than butter. Excess consumption of protein was found to increase the risk.

10.6 Malignant Lymphomas. Persson et al. (Ref. 206) conducted a case-control study of the relationship between occupation and development of Hodgkin's disease or non-Hodgkin's lymphoma. The 31 cases of Hodgkin's disease and 93 cases of non-Hodgkin's lymphoma obtained from a Swedish regional cancer registry were compared with 204 randomly selected, age-matched controls from the same residential area as the cases. All cases and controls were males between 20 and 80 years old. Occupational exposures were obtained by means of a questionnaire mailed to the study participants. Exposure times of greater than 1 year that had occurred between 5 and 45 years before the diagnosis were con-

sidered for inclusion in the study. Exposure to welding was associated with a marginally significant increased risk for non-Hodgkin's lymphoma (OR = 2.3, 90% CI = 1.0–5.1) but not for Hodgkin's disease.

10.7 Liver Cancer. All cases of primary liver cancer reported to the Finnish Cancer Registry in 1976, 1977, 1978, and 1981 were examined by Kauppinen et al. (Ref. 141). There were 344 cases available for study after elimination of those that could not be traced and those who did not respond. The age- and gender-matched controls consisted of 476 stomach cancer patients and 385 people who died from coronary infarcts. Employment history was compiled in all groups by means of a postal questionnaire sent to the closest available relative. The questionnaire included a specific question about the welding activities of the subjects. Cumulative occupational exposures garnered from the questionnaires were rated low, moderate, or heavy. In the case of welding fumes, heavy exposure was equated to at least 10 years' exposure to fumes at a level of 2.5 mg/m^3. A significantly increased risk of primary liver cancer was found among welders so exposed, both for men (OR = 4.16, CI = 1.24–13.9) and for both sexes combined (OR = 3.78 CI = 1.14–12.5). After adjustment for alcohol consumption, there was still a significant excess of liver cancer for men highly exposed to welding fumes. Excess primary liver cancer was also found among milkmaids, clerical workers, and men exposed to mineral dusts. Only in the case of milkmaids, who were probably exposed to cattle feed contaminated with aflatoxins, which are known carcinogens, did the authors find a plausible occupational etiology for the excess liver cancers. Since the positive association found in this study between liver cancer and welding has not been supported by the results of other studies, the authors suggested that future studies should be designed to test this possible association.

10.8 Cancers Associated with Electromagnetic Fields. Electric arc welders can be exposed to intense electromagnetic magnetic fields (EMFs) that emanate from the equipment used to generate and carry the electrical current to produce the arc (Ref. 257). There is no general agreement in the scientific community concerning whether EMFs at levels encountered by welders can interact with human tissue or which of the parameters of EMF exposure (wavelength, frequency, intensity, and duration) may be most important if such interactions exist. Some investigators have held that exposure to low-frequency EMFs may lead to adverse health effects, the most serious being leukemia and brain cancer. Most studies on the effects of EMFs have been conducted with electrical industry workers and welders because they are in the occupations most likely to experience frequent exposures to intense EMFs.

Theriault (Ref. 257) reviewed the literature concerned with the possibility of an association between cancer, especially leukemia and brain cancer, and exposure to EMFs in electrical utility workers and associated occupations. Most of the case-control studies reviewed by Theriault showed elevated odds ratios for leukemia among workers in electrical occupations associated with high exposure to EMFs. Only three of the 11 electrical worker cohort studies reviewed by Theriault revealed any excess leukemia among the groups of workers presumed to have been exposed to EMFs. The conflicting results between case-control and population studies have no ready explanation. In his review of the effects of EMFs on welders, Theriault cited the report by Stern (Ref. 247) who had evaluated 15 studies of the incidence of cancer among welders which did not show an excess of leukemia. The results of a case-control study conducted by Preston-Martin (Ref. 209), which showed a high correlation of welding with myeloid leukemia, were regarded by Theriault as "remarkable, in view of the several negative studies…cited." Theriault suggested that there is a possibility for confounding exposure to carcinogenic substances among all of the EMF-exposed populations. According to Theriault, "The evidence that EMF causes cancer in man is still evading us."

In a recent case-control study conducted in Torino, Italy, Ciccone et al. (Ref. 45) examined the association between myeloid leukemia and occupational exposures to solvents and EMFs. The study population consisted of 50 patients with acute myeloid leukemia, 17 with chronic myeloid leukemia, 19 with myelodysplastic syndromes, and 246 controls. A statistically nonsignificant excess of cases was found among those exposed to extremely low-frequency EMFs (OR = 1.6, CI = 0.6.–4.1). There was no excess of these cancers among those exposed to welding fumes, but carpenters and welders as a combined group had a nonsignificantly elevated risk (OR = 2.1, CI = 0.6–7.4).

Richardson et al. (Ref. 214) investigated the association between acute leukemia and occupational exposure to EMFs in a case-control study conducted in two hospitals in Paris, France, and environs. The study involved 204 cases of adults over 30 years of age diagnosed with leukemia between 1984 and 1988. It was carefully controlled for occupational and medical exposure to ionizing radiation. An increased risk for acute leukemia was found to be associated with occupational exposure to EMFs. However, the odds ratio was increased, and only became statistically significant, when arc welders were removed from the group considered to be exposed to EMFs. The authors concluded that there is consistent support for the hypothesis of a relationship between EMFs and development of leukemia, "…despite the fact that…exposure to EMF is only extrapolated from

professional classification or job description rather than direct measurements of the fields." This conclusion is counter to that of Theriault (Ref. 257) and is also contradicted by McBride and Gallagher (Ref. 169) who reviewed epidemiology studies of electric and magnetic fields between 1979 and 1991 and stated that "until new research information is available, it is impossible to conclude from the available evidence that there is a causal relationship between EMF and cancer."

The role of occupational exposure to heat or to EMFs in the development of male breast cancer was examined in a case-control study by Rosenbaum et al. (Ref. 222). The 71 male breast cancer cases used in the study were recorded in the western New York section of the New York State Tumor Registry between 1979 and 1988. The age- and race-matched control population of 256 was drawn from men residing in the 8 counties covered by the tumor registry who had participated in a cancer-screening program conducted in the same geographical area. Individuals with a previous cancer history or a positive screening test were excluded. A significantly elevated relative risk (OR = 2.5, CI = 1.02–6.0) for the disease was found in the occupations associated with heat exposure (mainly foundry workers, boiler operators and firefighters). The EMF-exposed group, which included welders, was not associated with any increased risk for breast cancer (OR = 0.6, CI = 0.2–1.6).

In summary, there is limited evidence suggesting an association of leukemia and brain cancer with EMFs but this view is not universally accepted. Reviews of the literature concerned with EMFs and cancer disagree about whether there is sufficient evidence to establish a causative link, and there is even less evidence linking the development of cancers with EMF exposures in welders. Richardson et al. (Ref. 214) only found a statistically significant link between EMFs and leukemia when they eliminated welders from the EMF-exposed population. Ciccone et al. (Ref. 45) found no association between leukemia and welding.

11. Metal Fume Fever

Metal fume fever is an acute illness of short duration with flu-like symptoms, caused by inhalation of metal oxide particles. Symptoms develop within several hours after exposure and include chills, fever, muscle or joint pain, difficulty breathing, headache, sore throat and chest tightness. Metals known to cause metal fume fever include zinc, copper, magnesium, aluminum, antimony, iron, nickel, cadmium, and tin. A short-term tolerance can develop with repeated exposure to metal fumes, and episodes of metal fume fever frequently occur on Mondays after a weekend break from exposure.

Offermann and Finley (Ref. 192) described a typical case of metal fume fever. A 24-year-old male welder spent the day welding a nongalvanized steel pipe in an unventilated area. Within an hour after leaving work, he developed a dull constant headache, nonproductive cough, dyspnea, fever, chills, and joint and muscle pain. He reported to the emergency department of a Norfolk, Virginia, hospital where tests showed that his white blood cell and platelet counts, temperature, and carboxyhemoglobin were elevated. All other clinical and laboratory tests, including a chest X-ray, were normal. He was diagnosed as having metal fume fever. By the next morning, his fever abated and the hematologic parameters and blood carboxyhemoglobin concentration returned to normal.

In a second case described by Koh and Chia (Ref. 150), a 40-year-old Chinese welder reported to an occupational health clinic in Singapore with complaints of painful sore eyes, dry cough, and muscle pain. He was diagnosed as having photokeratitis (arc eye) and metal fume fever.

Gordon et al. (Ref. 94) tested the human response to concentrations of zinc oxide equivalent to the TLV of 5 mg/m^3. Four male volunteers without previous exposure to metal fumes were exposed for 2 hours via face mask to 5 mg/m^3 ultrafine zinc oxide (ZnO) particles (particle size: 0.06–0.52 μm). Each of the subjects developed one or more symptoms of metal fume fever within 6 to 10 hours after exposure. No changes in pulmonary function were detected. All symptoms were gone within 24 hours after exposure. Similar exposures caused acute inflammatory changes in the lungs of guinea pigs and rats, but not rabbits. (The studies in laboratory animals are discussed further in Subsection 28, Metal Fume Fever). The investigators concluded that the TLV may not protect workers against the development of metal fume fever.

While the etiology of metal fume fever has been understood for over a century (Refs. 192 and 205), the mechanism by which inhaled metal oxides cause the systemic flu-like response is not yet established. Results of a preliminary study published in 1991 by Blanc et al. (Ref. 23) suggested that inflammatory processes in the lungs may play a critical role in this disorder. Leukocyte (white blood cell) populations were examined in BAL fluid obtained from 14 men at 8 and 22 hours after welding galvanized mild steel for 15 to 30 minutes under controlled conditions. They found that populations of cells essential to inflammatory processes (polymorphonuclear leukocytes (PMNs) and macrophages) increased in the BAL fluid during the first 22 hours after exposure to zinc oxide fumes.

Once inhaled, foreign particles are ingested or phogocytosed by alveolar macrophages in the lungs. When activated, these cells release mediators or cytokines into the surrounding milieu which can elicit reactions in dis-

tant cells or tissues. Blanc postulated that cytokines released from leukocytes responding to inhaled metal oxide particles are responsible for the systemic, flu-like symptoms characteristic of metal fume fever.

In their preliminary study (Ref. 23), Blanc et al. were unsuccessful in detecting the cytokines interleukin-1 (IL-1) and tumor necrosis factor TNF in the BAL fluid obtained from welders after exposure to zinc oxide fumes. In further attempts to identify mediators that may be responsible for the systemic effects associated with inhalation of zinc oxide fumes, they continued their study with nine more volunteer welders (five of whom were female) bringing the total number of welders in the study to 23 (Refs. 21 and 22). In addition to repeating the analyses conducted in the preliminary work, they collected BAL fluid at an earlier time after exposure and determined the level of three more cytokines in the BAL fluid. Arc welding of galvanized mild steel was conducted for 15 to 30 minutes under the same conditions as in the earlier work. Zinc oxide concentrations in breathing zone samples were determined for each of the welding exposures. BAL fluid was collected from six of the welders at 3 hours after exposure and from the remainder at either 8 or 22 hours after exposure. The concentrations of the cytokines TNF, IL-1, interleukin-4 (IL-4), interleukin-6 (IL-6), and interleukin-8 (IL-8) were determined with immunochemical techniques in BAL fluid from these volunteers and from frozen samples collected from the 14 volunteers who participated in the earlier study.

Concentrations of TNF, IL-1, IL-6, and IL-8 were significantly greater in BAL fluid collected from exposed welders than in that collected from 17 nonexposed controls. IL-4 was not detected in BAL samples from either welders or controls. Tumor necrosis factor, IL-6, and IL-8 varied with time after exposure and with the intensity of exposure. IL-8 peaked at 8 hours and IL-6 levels increased steadily with time after exposure and reached a maximum concentration at 22 hours. TNF concentrations were elevated at 3 hours but not at the later time points. In the previous study (Ref. 23), this elevation in TNF was not detected because samples of BAL fluid were not collected until 8 hours after 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. Based on the finding that TNF was the only cytokine studied that was elevated at 3 hours, the earliest time point studied after exposure, they postulated that TNF is a key mediator of metal fume fever. IL-6 and IL-8 elevations also occurred in association with zinc oxide fume exposure and may be involved in later aspects of the syndrome. For example, IL-8 is a potent chemical attractant for PMNs. The increase in IL-8 concentration seen 8 hours after exposure may be related to the influx of PMNs which reaches a peak 22 hours after exposure (Ref. 21).

12. Effects on the Ear

Although uncommon in welders, injuries of the ear can have serious sequelae. The most frequently encountered ear injuries in welders include burns of the outer ear and ear canal and perforation of the tympanic membrane. A case of hearing loss following an incident in which a welding spark entered the left ear of a 40-year-old welder was reported by Seiler (Ref. 231). The welder did not seek medical attention at the time of the accident and he gradually lost hearing acuity in his left ear. Medical examination 6 years later indicated that the ear drum had not been perforated and no foreign body could be found. However, the middle ear was filled with fluid and a small perforation was found at the base of the ear canal. Inflammation of the middle ear eventually resulted in cholesteatoma, a benign tumor-like mass in the middle ear.

Panosian and Dutcher (Ref. 201) described two cases of ear burns which resulted in damage to the facial nerve. In the first incident, a spark flew into the right ear of a man who was welding. Examination revealed numbness of the right side of the tongue, decreased hearing in the right ear with an echo sensation, mild right facial droop and weakness, and a small perforation of the tympanic membrane. By 14 months after the injury, the moderate right-sided hearing loss continued, but his facial nerve motor function had returned to normal.

In the second case, a 35-year-old man was using an acetylene torch for repair work under his car when a piece of molten metal fell into his left ear. He heard a loud hissing sound, which was followed immediately by pain, dizziness, deafness in the injured ear, and an abnormal sensation on the left-side of his face. Examination at an emergency room revealed left-sided facial paralysis, and a perforation of the tympanic membrane. A piece of metal was surgically removed from the left middle ear space. Examination one year later revealed a profound hearing loss in the injured ear and moderate partial paralysis of the facial nerve. In a similar incident, described by Chen and Caparosa (Ref. 40), a 42-year-old male was welding underneath a car when a spark entered his ear canal. He experienced pain, dizziness, total hearing loss, and facial paralysis.

Panosian and Dutcher (Ref. 201) concluded that, although injuries to the ear are rare among welders, the risks warrant the use of ear protection during welding operations. The authors concurred with the findings of Fisher and Gardiner (Ref. 74) that the conventional welder's visor helmet is inadequate for protecting the

ears when worn in the vented position or when working overhead or in cramped conditions. 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. This standard states that helmet shields must protect to a vertical line behind the ears, and that properly fitted flame-resistant ear plugs or their equivalent should be used when hazards to the ear canals exist.

13. Effects on the Eye and Vision

Masilamani (Ref. 167) surveyed the cases of occupational eye injuries treated at the eye clinic of the Government General Hospital in Seremban, Malaysia, during the year 1991. Of the 893 eye injury cases seen at the hospital, 52%, were of occupational origin and, of these, 15% occurred in welders. Eye injuries severe enough to cause loss of visual acuity were seen in 6% of the work-related cases. Extraocular foreign bodies accounted for 42% of the occupational injuries; 13.5% of the persons with this type of injury were welders. Photokeratitis (arc eye) was noted in 14 of the patients, all but one of whom were welders.

Welding-related lesions of the retina are less common than lesions of the outer surface of the eye. When they occur, retinal lesions are usually found in the macula, a small oval area on the inner surface of the retina near the optic nerve, or in the fovea, an area in the center of the macula that is essential for vision. Lesions of the macula are generally thought to result from exposure to infrared radiation.

Lindblom (Ref. 160) described the case of a 52-year-old welder who experienced an acute loss of vision. Examination revealed pigmented scars in the fovea of both eyes, while the rest of the retina appeared normal. The appearance of the fovea did not improve over the next 4 years. The patient had performed GMAW for 15–20 hours per week for several years before suffering from loss of vision. He did not use a helmet when welding. Lindblom speculated that the injury may have been due to welding, but he recognized that it was not possible to prove the relationship.

Three cases of welding arc maculopathy were described by Fich et al. (Ref. 71). The first was a 19-year-old male arc welding student who, one evening after welding, experienced difficulty reading but had no ocular pain. Examination of his eyes revealed oval lesions on the maculae of both eyes. He was treated with steroids for 4 days. The lesions resolved and his vision returned to normal within 6 months. The patient had worn a protective visor while welding but immediately after welding, he routinely removed the visor and closely examined the metal which was still "red- or white-hot." His injury was attributed to visible or infrared (IR) radiation.

A second case involved a female welding student who performed GTAW of stainless steel. Her visor was tinted on the lower half only. As in the previous case, she experienced loss of vision without ocular pain. Examination revealed lesions on the fovea of both eyes. Seven months after the incident, the lesions were still present and her visual acuity was still highly impaired. The lesions were attributed to IR radiation entering through the untinted part of the visor, since most of the UV radiation would have been absorbed by the untinted glass.

The third case involved a 38-year-old male who was taking an arc welding course. He experienced keratoconjunctivitis and loss of vision after welding for 2 days without wearing a protective visor. Examination of the eyes revealed macular lesions. Some improvement in his vision and in the macular lesions occurred within 4 months.

14. Effects on the Skin and Connective Tissue

14.1 Thermal Burns. Thermal burns caused by contact with hot metal fragments are a common occurrence among welders (Ref. 96). To identify the population at risk from work-related burns, Khoo et al. (Ref. 145) surveyed the 362 cases of burn injuries admitted to the Burns Center at the Singapore General Hospital between April 1, 1992, and March 31, 1993. Work-related injuries comprised 45% of the burns treated during this period. Of these, 52.8% were caused by explosions or flame, 24.5% were caused by scalding, 10.4% were electrical, 6.1% were chemical, and 6.1% were contact burns. The majority of burns were received by workers in the manufacturing sector, and the largest number of patients in this sector were from the shipbuilding and metalworking industries. Burns among workers in this sector were frequently due to exposure to flame, explosion of combustible liquids, and contact with intense heat sources such as welding torches and furnaces.

Three cases of spot welders with severe, persistent dermal wounds on the hands were described by Giddins and Wilson-MacDonald (Ref. 90). The wounds were characterized by extensive necrosis and bacterial infection. Treatment included removal of imbedded metal fragments and excision of necrotic tissue. 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. X-ray examination revealed a 3-cm area in which metal particles were scattered beneath the skin. Treatment involved immobilizing the finger and administration of a course of penicillin. The affected tissue did not become necrotic. Metal particles were eventually extruded without surgical intervention and complete recovery ensued. This injury was resolved using less-intrusive methods than were required in the preceding 3 cases (Giddins, Ref. 90), presumably because of the small amount of injected metal. Almind and Broeng stressed the need for rapid evaluation and treatment of this type of injury.

14.2 Chronic Actinic Dermatitis. Chronic actinic dermatitis is an extreme form of sensitivity to ultraviolet light. People with this condition can develop erythema (redness of the skin) in response to unusually low level exposures to UVB (280–315 nm), UVA (315–400 nm), and possibly visible light with wavelengths between 400–600 nm. This photosensitivity is found mostly in adult and aging men; the underlying mechanism of this condition is unknown.

The case of a 45-year-old welder with chronic actinic dermatitis was described by Roelandts and Huys (Ref. 217). After working for 25 years, he developed problems on exposed areas of his skin after welding. He first 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. These symptoms were most severe 24 hours after exposure and subsided within 4 days. He eventually began to experience a prickly skin sensation when exposed to fluorescent lamps or sunlight. Skin tests revealed an unusual sensitivity to UVC (100–280 nm) at 254 nm. (UVC from solar radiation is filtered out by the atmosphere and, thus, most exposures to UVC result from industrial processes.)

14.3 Hypersensitivity to Nickel. Contact hypersensitivity to nickel is unusually common among the general population. In his review of this condition, Menne (Ref. 173) cited data which indicate that the worldwide prevalence of nickel allergy is 7% to 10% in females and 1% to 2% in males. Most cases of primary nickel sensitization result from prolonged nonoccupational skin contact with objects plated with nickel or nickel alloys, such as costume jewelry and inexpensive watches. In industrial settings, occupational nickel sensitization is relatively rare. It usually starts as eczema on the skin of the hand and eventually spreads to the forearms. Menne cited metalworking and welding as occupations with significant nickel exposure. He indicated that primary nickel dermatitis causes only minor discomfort and has a good medical prognosis. If the condition is left untreated and intensive nickel contact continues, it may become chronic and can spread to skin sites distant from the area where dermatitis initially occurred.

14.4 Scleroderma. Scleroderma is an uncommon disease which causes the deposition of fibrous connective tissue in the skin, lungs, and other internal organs. It also causes vascular and immunological abnormalities. Its most common feature is thickening of the skin on the back of the hands and forearms, and the central part of the face. Raynaud's phenomenon, characterized by intermittent blanching and numbness of the fingers, is often an early sign of the disease. Scleroderma 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) published case histories of four patients with scleroderma, one of whom was a 44-year-old welder who had been exposed to hand-arm vibration from the use of a high-speed reamer, chipping hammer, impact wrench, and huck gun (described as a one-motion riveting tool). He experienced difficulty swallowing and his pulmonary function worsened with time. Pleural thickening, with interstitial fibrosis, was seen in the lungs. His hands gradually became swollen, Raynaud's phenomenon developed in his right hand, and after 8 years exposure, ulceration of the finger tips forced him to stop working.

15. Effects on the Nervous System

15.1 Motor Neurone Disease. Motor neurone disease (MND) is a fatal, progressive, neurodegenerative condition. Three types of MND have been identified: amyotrophic lateral sclerosis (ALS or Lou Gehrig's disease), progressive bulbar palsy, and progressive muscular atrophy. All usually lead to death within 2 to 3 years. While the cause of MND is not established, there is wide support for the hypothesis that environmental exposures may be involved in its etiology.

A case-control study conducted by Gunnarsson et al. (Ref. 98) examined risk factors for MND. A survey of neurology and internal medicine departments of hospitals in nine counties with a total population of 1.2-million inhabitants in southern Sweden revealed 112 MND cases. Questionnaires concerning occupational exposures, medical history, lifestyle factors, and dietary habits were sent to each of the MND cases and to 500 age-matched area residents (controls) randomly selected from the National Population Register. The study population consisted of the 92 cases and 372 controls who responded to the questionnaires. A family history of Alzheimer's disease, Parkinson's disease, ALS, or thyroid disease was found to be a significant risk factor for MND (OR = 2.1, CI = 1.0–4.3). Employment in electrical occupations (OR = 6.7,

CI = 1.0–32.1) and welding (OR = 3.7, CI = 1.1–13.0) were also associated with a significant risk of MND. Exposure to any solvent increased the risk of MND in 45- to 59-year-old subjects. The risk for MND was greatest among men with a family history of neurodegenerative or thyroid disease combined with occupational exposure to solvents (OR = 15.6, CI = 2.8–87.0). This combination of risk factors occurred in seven cases and three controls. On the basis of a study which showed that ALS patients are less capable of detoxifying certain chemicals than are healthy individuals (Ref. 106), Gunnarsson (Ref. 97) speculated that the altered metabolism of toxic substances might lead to a buildup of toxic materials in the nervous system which could be responsible for initiating neurodegenerative processes.

Camerino et al. (Ref. 38) administered computerized tests for neurobehavioral abnormalities, including reaction time, learning ability, visual recognition, and mood states, to workers exposed to potential occupational neurotoxins. Eighteen welders exposed to aluminum at breathing zone concentrations of 1.6 to 3.5 mg/m^3 for less than one year were included in the exposed population, along with ferromanganese production workers and populations of workers exposed to lead and zinc or to petroleum and organic solvents. Only the workers exposed to lead and zinc displayed abnormalities in these tests. There was no difference between the performance of welders and controls in any of the tests.

15.2 Multiple Sclerosis. Multiple sclerosis is a degenerative condition of the central nervous system that destroys the protective myelin sheath that surrounds the axons of some nerve fibers. Its cause is unknown but both genetic and environmental factors are thought to be involved. Studies of the relationship between occupational exposures and multiple sclerosis have been inconsistent.

In 1988, Flodin et al. (Ref. 75) reported that Swedish men who had been exposed to both organic solvents and welding had an increased risk of multiple sclerosis. These investigators later conducted a similar study in a different geographical area of Sweden (Ref. 154). In the latter work, the multiple sclerosis cases were taken from the neurological departments of hospitals in the Swedish provinces of Jonkoping and Kalmar. All of the 91 cases were diagnosed between 1983 and 1988. The 348 referents were randomly selected from the population residing in the same area. Data concerning occupational exposure were obtained by questionnaire. Exposure to solvents (in particular, kerosene), radiological work, and occupational contact with domestic animals (e.g., dogs, cats, poultry and horses) was associated with an elevated risk for multiple sclerosis. The study did not corroborate their previous findings (Ref. 75) that combined exposure to organic solvents and welding was a risk factor for multiple sclerosis.

Gronning et al. (Ref. 95) also examined the relationship between multiple sclerosis and welding. These investigators performed a case-control study which included 139 patients from Hordaland, Norway, who developed signs of multiple sclerosis between 1976–86 and were diagnosed by 1986. The 161 controls were hospital patients with unrelated diseases. There were no significant differences between multiple sclerosis patients and controls with regard to exposure to organic solvents or combined exposure to organic solvents and welding. No association was found between occupational exposures to organic solvents, alone or in combination with welding, and the development of multiple sclerosis.

15.3 Aluminum Exposure. Animal studies and findings in kidney dialysis patients have suggested that aluminum may act as a neurotoxin. The neurological syndrome associated with aluminum accumulation in dialysis patients is characterized by speech disturbances, seizures, and a decline in cognitive function. Recent studies suggest an association between inhaled aluminum and neuropsychological symptoms in miners (Ref. 215), aluminum foundry and smelter workers (Refs. 119 and 281), and aluminum welders (Refs. 238 and 100).

In 1994, 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 performed GMAW of aluminum for the 4 years preceding the study. Central nervous system function was examined with neuropsychological tests, symptom and mood questionnaires, and electroencephalography (EEG). The mean aluminum concentrations in serum and urine were 0.21 (range 0.03–0.64) and 2.8 (range 0.9–6.1) µmol/L, respectively. These levels were 3.5 and 8.5 times higher than the respective concentrations in an occupationally unexposed reference population. The welders performed normally in tests for psychomotor, visual, and spacial abilities. A negative association between mood disturbances and serum aluminum was found. Results of memory tests and visual reaction times suggested a slight deficit in short-term memory, learning, and attention. The correlations between the neuropsychological test results and aluminum concentrations in serum and urine were inconsistent. Changes in EEG activity in the frontal region of the brain appeared to have been related to aluminum concentrations in serum. They concluded that because of the small sample size, the study did "not allow any definitive conclusions" but, rather, it suggested that aluminum uptake from welding exposures may have an effect on central nervous system function.

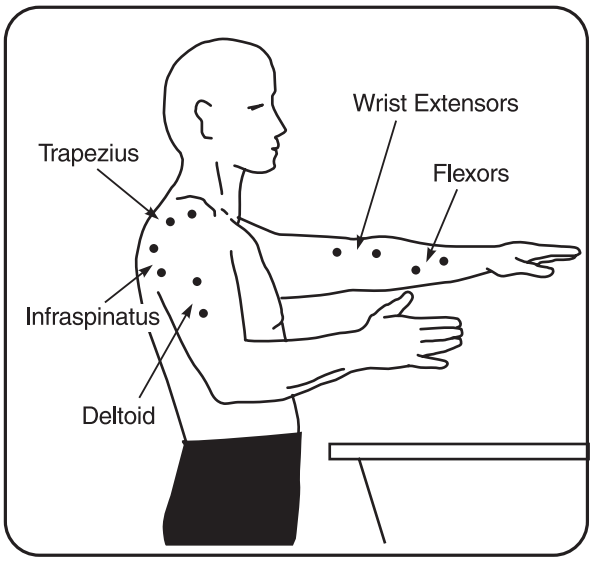
To estimate maximum exposure levels to aluminum that could be used as guidelines to protect welders from developing impaired central nervous system function, Sjogren and Elinder (Ref. 235) examined data from studies of dialysis patients with abnormal psychomotor function and from studies of aluminum retention in welders. Sjogren et al. (Ref. 236) had earlier shown that the retention of aluminum in the body increases with years of exposure. The half-life of aluminum in urine from aluminum welders with less than one year experience was about 9 days and that from aluminum welders with more than 10 years experience was about 6 months or longer. Bone analyses in two men with 20 years of welding experience showed aluminum levels that were three to four times higher than those in reference populations and up to two times higher than those in dialysis patients (Ref. 64). These results indicated that aluminum is retained in the bodies of aluminum-exposed welders. Based on reported mean aluminum concentrations of about 60 µg/L in serum from dialysis patients with abnormalities in psychomotor function, Sjogren et al. determined that equivalent concentrations of aluminum in blood and urine of aluminum-exposed welders with normal kidney function, would be 64 µg Al/L and 330 µg Al/L, respectively. They calculated that this post-shift urine concentration corresponds to an environmental concentration of about 1.6 mg/m^3 in aluminum welders who had been exposed for 40 years or 4.9 mg/m^3 in those exposed for 20 years. The TLV for aluminum is currently 5 mg/m^3. In 1992, the occupational exposure limits in Germany, Sweden, and the United Kingdom were 6, 4, and 10 mg/m^3, respectively. Based on the above calculations, Sjogren and Elinder (Ref. 235) recommended that the time-weighted average occupational exposure limits should not exceed 1 mg/m^3.

16. Effects on the Musculoskeletal System

Welders can be subjected to ergonomic stresses caused by the dimensions and weight of the welding equipment and by the positions they must often assume to perform the work. Schneider and Susi (Ref. 228) analyzed ergonomic stresses in construction and concluded that "awkward postures, occasional high-force requirements, static postures, repetitive movements…and lifting," were possible ergonomic problems for structural steel workers.

Tregaskiss and Dutta (Ref. 261) performed a study of eleven commercial and five prototype gas metal arc welding guns to examine the relationship between their physical characteristics and the muscular forces required to operate them. Four experienced welders were fitted with electromyograph (EMG) electrodes taped to muscles of the forearm and shoulder as shown in Figure 3. Maximum voluntary contraction (MVC), a measure of maximum strength, was obtained for each muscle using a dynamometer. EMG signals generated by muscle contraction were recorded while the welders executed four welds in each of three positions (flat, vertical, and overhead) with each gun. The EMG measurements for each muscle were expressed as the ratio of the intensity of the EMG signal generated while welding to the intensity of the signal generated at the MVC. Care was taken to ensure that the welders' posture and the physical arrangements of cables and other equipment were kept the same for all of the guns tested. In addition to the EMG measurements, the welders provided their own assessment of the maneuverability, comfort, and manageability of each of the welding guns. Five of the commercial guns were 300-ampere (A), and six were 400-A. As would be expected, the heavier 400-A guns generally required greater muscle activation, but one 400-A gun required less muscle activation than four of the five 300-A guns.

Physical characteristics (weight, grip circumference and shape, trigger activation force, and vibration) were ranked for the guns tested and compared with the results of the EMG measurements and the welders' ratings. The agreement between muscle activation readings and the



Activation of the muscles indicated with arrows was measured during GMAW with several different welding guns.

Figure 3—Arm and Shoulder Muscles Used During Welding (Ref. 261)

ratings based on the physical characteristics of the different guns, supported by the welders' assessments, demonstrated that physical measurements can be used to design or to choose gas metal arc welding guns with the least potential for causing neuromuscular harm to the welder.

Strakova and Polach (Ref.248) examined 60 Czech welders (49 men and 11 women) who had neuromuscular disease in the dominant hand or arm. To determine the cause of the injuries, the authors conducted a study of the forces necessary to open welding-grip arms while changing electrodes. (The authors referred to the clamp which is manually opened during the insertion or removal of electrodes from the electrode holder as the "welding grip.") For each exchange, the grip must be opened twice. A static force is required to insert the electrode, and a predominantly dynamic force is used for its removal. The static force required to insert a new electrode into four different welding grips was tested using a group of 134 welders from two Czech factories. The grips tested required hand spans ranging from 72 to 100 mm, and required gripping forces of 150 to 270 newtons (N), as measured using a transducer. The dimensions of the dominant hand of each participant were recorded, and a transducer was used to measure maximum gripping forces that the welders could exert over spans equal to those of the welding-grip arms. In groups of welders ranked according to age, maximum gripping forces were approximately the same within each age group for grip spans of 72 or 80 mm, but they declined by 35% in all age groups when the span was increased to 100 mm. Gripping strength measurements were also ranked according to the subjects' hand dimensions, and the investigators found that even with smaller hands "a reasonable grip" could be achieved with a grip span of 80 mm or less, but that the 100-mm span was too wide for most normal hands. Only one of the four grips tested, which had a gripping span of 80 mm and required a gripping force of 150 N, 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. These included assistance in handling of heavy workpieces, workpiece positioners that can be used to avoid awkward working postures, and support for welding cables. 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. Each workplace is equipped with local exhaust and fume-extracting gas metal arc welding guns. Grinders with integral exhaust capture most of the respirable particles. All workplaces are equipped with lift tables and 1-ton hoists. Heavier items are handled with a moveable overhead hoist. Power supplies can either be mounted on the wall or suspended from the service beam. Welding curtains are also suspended and retractable for ease of movement of material. Workplace walls are provided with noise insulation, and some of them are movable to facilitate bringing larger workpieces into the workplace.

As part of a study described earlier (see Subsection 8.2, Asthma and Bronchitis), Wanders et al. (Ref. 275) determined the incidence of locomotor disorders leading to termination of employment as a shipyard welder. Detailed information was available for 418 welders and 1130 controls, all of whom had worked in the same shipyard and had retired, died, or been discharged between 1966 and 1988. While the primary hypothesis of this study was that medical disability due to musculoskeletal disorders would be higher among welders than among controls, no such difference was found between the two groups.

17. Effects on the Kidney

17.1 Cadmium. Chronic exposure to low concentrations of cadmium fumes can result in kidney tubular damage. This disorder is first manifested by urinary excretion of low molecular weight proteins, such as alpha1-microglobulin, beta2-microglobulin, and retinol-binding protein. Holmquist et al. (Ref. 117) found that the protein apolipoprotein D (apo-D) could be used as an additional marker for kidney malfunction. To evaluate the effect of renal tubular damage on the concentration of this protein, they measured the urinary concentrations of apo-D and alpha1-microglobulin in the urine of eight welders who had been exposed to cadmium-containing welding fumes for 20 years. All of the welders had elevated levels of cadmium in the blood and urine. The average concentrations of urinary apo-D and alpha1-microglobulin were 3 and 15 times higher, respectively, than those in 50 healthy males with no known cadmium exposures. While apo-D became elevated in the urine of cadmium-exposed workers, it is a less-sensitive indicator of exposure than the routinely used marker alpha1-microglobulin. However, the investigators concluded that, because 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.

17.2 Chromium. Acute exposure to high concentrations of hexavalent chromium can cause kidney disease. The effects vary with the dose and can range from tubular proteinuria to acute tubular necrosis and kidney failure. Based on the known effects of acute exposure to high concentrations of chromium on the kidney, Wedeen and Qian (Ref. 278) conjectured that long-term exposure to

low levels of chromium could also cause kidney tubular disease. They maintained that the effects of chronic chromium exposure on the kidneys have not been adequately studied and stressed the need for large-scale, prospective case-control epidemiologic studies to demonstrate whether or not delayed renal effects can result from low-level, long-term exposure to chromium.

The hypothesis put forth by Wedeen and Qian, that chronic exposure to low levels of chromium could cause kidney disease, was tested, in part, by a study conducted by Vyskocil et al. (Ref. 274). This study searched for urinary markers of impaired kidney function in 52 male stainless steel welders with an average of 18 years exposure to chromium-containing fumes. The workers were employed at a machine factory where SMAW of chromium-nickel alloyed steel was conducted. Fifty-one age-matched, nonexposed male office workers at the same factory served as controls. For the welders, the mean breathing zone concentration of water-soluble hexavalent chromium compounds was slightly higher than the TLV (50 $\mu g/m^3$) and that for nickel was about half the TLV (50 $\mu g/m^3$). Mean urinary levels of chromium and nickel were ten and two times higher, respectively, than levels found in controls. The urinary excretion of total proteins, albumin, protein-1, transferrin, retinol-binding protein, lactic dehydrogenase, beta-2-microglobulin, lysozome, and beta-N-acetylglucosaminidase did not differ significantly between welders and controls. The only significant finding was that beta 2-microglobulin was slightly increased in the nine welders who had a urinary chromium concentration of greater than 64.5 nmol/mmol creatinine. The authors did not consider this observation to be evidence of significant proximal tubular impairment since the urinary excretion of other low-molecular-weight proteins was normal. On the basis of these results, the investigators concluded that if hexavalent chromium 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.

18. Effects on the Cardiovascular System

To determine the occupations with the greatest risk of heart disease in Denmark, Tuchsen et al. (Ref. 263) linked census data on the Danish working population to hospitalization records between 1981 and 1984. All subjects between the ages of 20 and 59 years were followed for 4 years for death and hospital admissions for ischemic heart disease. Included in the study were 1 293 888 men with 15 631 first hospital admissions for ischemic heart disease, and 1 285 508 women with 4253 first hospital admissions for ischemic heart disease. The standardized hospitalization ratio (SHR: number of cases observed for an individual occupational group divided by the number observed for the whole population) was determined for each occupational group. No significant excess risk of heart disease was found for male welders but the occupational group defined as female "unskilled welder, steel tube, and sheet construction worker" was found to have an excess risk of ischemic heart disease with an SHR of 172.

Workers with long-term exposure to tools that cause hand-arm vibrations may be susceptible to Raynaud's phenomenon or vibration-induced white fingers (VWF). This vascular syndrome worsens with continued exposure to vibration and does not remit with cessation of exposure (Ref. 122). This syndrome has occasionally been noted in welders and is usually attributed to the use of pneumatic grinding and chipping tools. The pathogenetic mechanism of VWF is not understood. Reports of increased whole blood viscosity, or changes in plasma viscosity, have appeared in the literature. Plasma viscosity has been reported to be affected by concentrations of plasma proteins such as immunoglobulin-M (IgM) and fibrinogen. Toren et al. (Ref. 260) studied 34 men with confirmed cases of VWF to further investigate the potential association between VWF and plasma viscosity and plasma components. All participants were dock workers at a shipyard in Goteborg, Sweden. Ten were welders, and the remainder were platers, plumbers, repairmen, carpenters, and engravers. They had a mean exposure of 17.1 years to vibrating tools. Thirty foremen and office workers from the same shipyard, who had no exposure to tools that caused hand and arm vibration, served as controls. Approximately one-third of both the men with VWF and the controls were smokers. Plasma viscosity was measured at two shear rates in blood collected from VWF patients and controls.

At the lower shear rate, plasma viscosity was significantly decreased in the VWF patients. When the data were analyzed in terms of smoking habits, the decreased plasma viscosity was significant only among the ex-smokers. At the higher shear rate, a statistically significant decrease in plasma viscosity was observed only among the men with VWF who were current smokers. Plasma viscosity was not significantly associated with the length of exposure to vibrating tools. Blood concentrations of immunoglobulin, rheumatoid factor, fibronectin, fibrinogen, antinuclear antibody, and hemoglobin did not differ significantly between the VWF group and the controls. While the authors concluded that workers with VWF have decreased plasma viscosity and that the decrease is more pronounced among smokers, analysis of the data suggests that plasma viscosity is depressed only among VWF patients who are past or current smokers. The biological significance of this effect is unknown.

19. Effects on Fertility

Baranski (Ref. 12) reviewed the literature published between the late 1970s and 1992 on the effects of occupational factors on fertility and reproduction. He noted that designing human fertility studies is difficult because of the high prevalence of unsuccessful reproductive outcomes that normally occur in the general population. (An estimated 10%–15% of all married couples are believed to experience fertility problems.) Few of the studies examined by Baranski fulfilled the criteria of good study design because of factors such as small sample size, insensitive measures of effect, biased selection, recall and observation bias, poor control of confounding factors, bad definition of exposure, inability to analyze a dose-response relationship, and inadequate statistical analysis.

Baranski listed about 50 studies which examined the effect of a broad range of occupational exposures on male fertility. Only about 25% of these were found to be adequate in terms of parameters such as standardization of confounding factors, appropriate control group, statistical significance, and size of the study population. Seven of the studies considered by Baranski examined the effect of welding on the male reproductive system. Of these, three were considered to be adequate in terms of study design. One showed infertility in welders (Ref. 33), and another indicated sperm abnormalities (Ref. 180). The third study that met Baranski's design criteria showed no association between sperm abnormalities and welding (Ref. 132). Of the four studies of welders deemed inadequate by Baranski, one showed reduced fertility in welders (Ref. 26), one indicated hormonal imbalances (Ref. 27), and two indicated sperm abnormalities (Refs. 28 and 246).

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 non-welding metal workers and electricians who served as controls. There was no correlation between deterioration of any of the semen parameters tested and chromium levels in blood or urine. Concentrations of follicle stimulating hormone (FSH) and luteinizing hormone (LH) were also independent of chromium concentrations in blood and urine. 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. These results are consistent with those from an earlier study by Jelnes and Knudsen (Ref. 132) who found that semen quality was normal in stainless steel welders who were exposed to low levels of hexavalent chromium. Bonde and Ernst (Ref. 32) concluded that further research is needed to determine if the reproductive system is at risk in male welders with high exposures to hexavalent chromium.

Bonde (Ref. 29) also investigated whether or not heat associated with welding exposures could affect the reproductive system of male welders. In this work, they attempted to isolate the effects of exposure to radiant heat from the effects of exposure to welding fumes by using a group of welders with long-term moderate exposure to radiant heat who were highly protected from fume exposure by local exhaust ventilation and compressed air respirators (Ref. 29). The 17 welders who participated in the study performed SMAW of chromium alloyed steel containing 10%–13% chromium and 0.3%–0.8% nickel during the manufacture of headers for boilers at a facility which manufactured boilers for power stations.

The welders stood close to the piece they welded which was heated to approximately 240°C; insulating mats were used to reduce exposure to heat. They worked in this position about five hours a day. The globe temperature ranged from 31.1° to 44.8°C at 20 cm from the workpiece. Skin temperature rose an average of 1.4°C in the groin and 3.0°C on the back of welders during periods of exposure to radiant heat. Chromium concentrations in urine samples collected from welders before the workshift were slightly higher than those in samples from the metal workers. Post-shift urine samples contained twice as much chromium as pre-shift samples taken on the same workday, indicating that the welders were not completely protected from exposure to fumes.

Semen was obtained from welders immediately after a 4-week holiday and during weeks 4–8 and 12–32 after resuming work. The quality of semen obtained from the welders during periods of heat exposure (e.g., between weeks 6 and 32 after resuming welding) was compared with that from 54 non-welding metal workers who had participated in a previous study (Ref. 27) and 19 flexoprinters. Each referent provided three semen samples which were collected at one-month intervals.

There were no significant differences in motile sperm count, sperm concentration and morphology between welders and either group of controls. A reduction in total sperm count of borderline significance ($p = 0.056$) was observed in welders compared with metal workers and printers. In a subgroup of ten welders, the proportion of sperm with normal shape, but not the total or motile sperm count, differed significantly in samples obtained at the end of the vacation period compared with samples obtained four or more weeks after resumption of welding. The proportion of sperm with normal shape increased after a break in exposure, as seen in another subgroup of eight welders in which semen was examined at week 32 and then again after the end of the next vacation period. No consistent changes were found in the

serum concentrations of the sex hormones testosterone, FSH and LH.

Bonde concluded that welders in this study experienced a reversible decrease in semen quality, most likely caused by a moderate exposure to radiant heat. While there was some uptake of chromium from the welding environment, he argued that the uptake was so low that "the role of chromium in the deterioration of semen quality could be discarded." Even though the statistical power of the study was low due to the small number of welders and the large variation in semen parameters both between and within individual subjects, Bonde maintained that the consistency of the findings suggested that the deterioration of semen quality was real and was related to exposure. Bonde recognized that the results of this study pertain only to the selected population of welders who had higher exposure to radiant heat than do welders in general. Reports of welders with constant excess heat exposure are rare, but such conditions were recently described in a brassware factory in India by Rastogi (Ref. 212).

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. The study cohort, identified from records of the Danish Pension Fund, consisted of 10 059 metal workers who were employed for at least 1 year between 1964 and 1984 at 79 Danish companies that manufactured stainless steel or mild steel articles. Only subjects who had been employed as mild steel welders, stainless steel welders, stainless steel grinders, or non-welding and non-grinding production workers (e.g., turners, fitters, warehousemen) were included in the study cohort. Data were collected from a total of 8376 metal workers who responded to postal questionnaires. These men had fathered 3569 children between 1973 through 1986. Data on pregnancy outcomes were obtained from the Danish Medical Birth Register. The cohort was divided into 3 categories: children at risk from stainless steel welding (n = 1317), children at risk from mild steel welding (n = 924), and children whose fathers were not welders (n = 1328). The gender ratio, birth weight, and incidence of preterm delivery and infant mortality were the same among children whose fathers were welders and children of non-welders. There were still no differences when the children at risk from stainless steel welding were analyzed in terms of fume exposure (SMAW versus GTAW) or length of time welding stainless steel.

Data on malignant disease in offspring were gathered from the entire population of 27 071 men, regardless of job title, who worked at the same 79 companies during the same time period as the study cohort. The incidence of malignant disease among the offspring of welders and non-welders was compared with the incidence of childhood malignancies in the general Danish population. Using Danish medical registers, data on childbirth and congenital malformations were compared with those obtained for the general population. The incidence of children with malignant disease was the same among the welders and non-welders from the 79 factories, and the incidence among these workers was very close to that expected on the basis of 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. There were no increases in organ-specific malformations in children of welders. On the contrary, a marked deficit in cardiovascular malformations was seen among children of both mild and stainless steel welders. The incidence of genital malformations was reduced among children of mild steel welders.

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 (OR = 1.9, CI = 1.1–3.2). The odds ratio was greater for pregnancies at risk from SMAW than from GTAW, which supported an exposure-response relationship. The investigators indicated that, due to flaws in the study design, follow-up studies were necessary to confirm this observation and they stressed that this finding should be interpreted cautiously.

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 original study was based on data obtained from the Danish Medical Birth Register, which the investigators later discovered is based on verbal reports given by the birthing mother regarding previous numbers of spontaneous abortions experienced. Hence, some of the date(s) of the spontaneous abortions reported by partners of welders may not have been accurate. The analysis was repeated with the same study cohort but using data from the National Inpatient Hospital Register which provides inpatient register information on spontaneous abortion. The new data showed that there was no increase in the occurrence of spontaneous abortions among wives of welders. The risk of spontaneous abortion was the same for mild and stainless steel welders and did not vary with duration of welding experience or intensity of fume exposure.

In 1993, Bonde (Ref. 30) reviewed the work he had conducted to date on the effect of welding on fertility in male welders (Refs. 26–29 and 32–34). These studies were motivated by the reports of two earlier investigations of Danish infertility clients, which reported delayed conception (Ref. 210) and reduced semen quality (Ref.

180) among welders. While Bonde concluded that his own studies indicate that welders may have reduced semen quality and an increased occurrence of infertility or reduced fertility, he acknowledged that "causal associations are far from unequivocal. Bias cannot be ruled out from any of the studies." He noted that the "rather small effects [observed] on semen quality and fertility" are vulnerable to unknown confounding factors and to all types of bias. He was surprised to find indications of reduced semen quality and fertility associated with welding of mild steel but not with the welding of stainless steel (Refs. 27 and 33). Bonde recommended that the suggested effects of mild steel welding on male fecundity should be corroborated by longitudinal controlled studies of semen quality examined before and during exposure and by prospective studies of fecundability in couples trying to conceive a child.

Moskova and Popov (Ref. 181) also examined the quality of semen from welders. Semen obtained from 30 Bulgarian welders was compared with that from 159 workers with no known welding experience or vocational exposures with potential reproductive risks. Information about the type of welding performed was not available. The incidence of deviations in sperm motility and morphology was significantly higher among the welders than among the controls ($p < 0.001$).

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. Thus, he contested Bonde's conclusion (Ref. 34) that the gender ratio of children fathered by welders is normal since Bonde's database consisted of 2241 children which would be much too small to have enabled detection of any abnormalities.

Schnitzer et al. (Ref. 229) conducted a population-based case-control study which examined whether or not there are associations between birth defects and several paternal occupations. The cases were infants born with a major birth defect registered with the Metropolitan Atlanta Congenital Defects Program between 1968 and 1980. Controls were selected from live births in the Atlanta area which were matched to cases on the basis of race, year, and hospital of birth. Parents of both case and control babies were interviewed to obtain relevant information including the job held by the father during the period 6 months before to 1 month after conception. The analysis included a total of 3739 cases and 2279 control infants. A number of associations were made between paternal occupation and birth defects. The strongest association was between the paternal occupation of fireman and babies born with cleft lip (OR = 13.3; 95% CI = 4.0–44.4). Other occupations associated with birth defects included painters, carpenters, and janitors. Welders were found to have offspring with a nonsignificantly elevated incidence of hydrocephalus. (OR = 2.8, CI = 0.8–9.9).

20. Effects of Manganese

Long-term exposure to manganese can cause a progressive nervous system disease with neurological and psychological manifestations. Early symptoms include apathy, lack of appetite, muscle spasm, and irritability. Signs of psychosis may develop, with euphoria, impulsive behavior, confusion, and aggression. Advanced stages resemble Parkinson's disease, with muscle weakness, muscle rigidity, tremors, and impaired gait.

In her report of OSHA compliance inspections at two welding facilities, Franek (Ref. 76) briefly 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." A blood sample taken in 1992 contained 11.3 µg manganese/L. The welder was ultimately removed from his job because of continuing problems associated with neurological damage attributed to manganese.

Nelson et al. (Ref. 189) described the case of a welder with severe manganese poisoning. The 44-year-old patient had been an arc welder for 25 years. For 10 years he repaired railroad tracks composed of Mn-steel alloy. For 15 years he worked indoors, with no local exhaust, where he welded and cut castings composed of 20% manganese. He began to experience severe headaches after 23 years of welding. Within 2 years, he had insomnia and lassitude, and he developed progressive confusion, poor memory, impaired cognition, paranoia, and loss of muscle control. When he ceased working after 25 years, computed tomography, electroencephalogram, blood chemistry, and thyroid function were all normal, but signals indicating manganese deposits were found in the basal ganglia and midbrain by magnetic resonance imaging (MRI). The signals were almost completely gone when MRI tests were repeated 6 months later, but his neuropsychiatric symptoms were unimproved. The authors suggested that, because MRI can detect manganese deposits in the brain before the toxic effects of manganese become manifested, this technique be used as an adjunct to environmental and biological monitoring for the evaluation and diagnosis of workers with high exposures to manganese.

21. Effects of Mercury

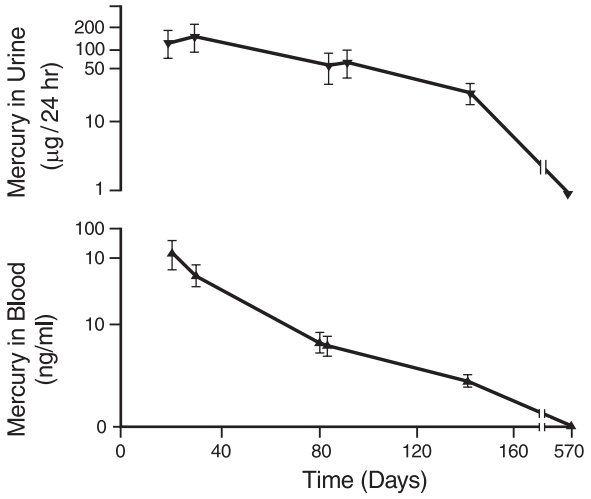
An incident in which 53 workers were exposed to mercury while performing maintenance work on a mer-

cury cell (mercury cathode used as an electrolytic catalyst) at a chlorine manufacturing plant in eastern Tennessee was described by Bluhm et al. (Ref. 24). Prior to the repair work, the mercury cell was shut down and the pipes were purged, but residual pools of mercury remained in many of the pipes after this procedure. Pipes were cut and welded with oxyacetylene torches which caused the mercury to volatilize. Vaporization and condensation of mercury occurred as the men worked on the pipes. The workers later reported that mercury which had condensed on the ceiling "rained down over them" and collected in their clothing and shoes, on exposed skin, and on the floor. The men worked in the area for up to 16 hours, and only a few wore protective clothing or masks. The men were not decontaminated before leaving the job site, and later investigation showed that floors, carpeting and washing machines in their homes were contaminated with mercury.

A number of the men became ill after the incident and, after a lapse of 2 to 5 weeks, 26 were referred to Vanderbilt University Hospital by their family doctors. At the time of referral, the men described symptoms such as headache, fatigue, fever, chills and decreased appetite. Some reported central nervous system symptoms, such as irritability, increased temper, mood changes, decreased sociability, and uncharacteristic violent behavior. Other symptoms, including respiratory tract congestion, shortness of breath, abdominal cramps, and diarrhea, were also reported. Gastrointestinal and pulmonary symptoms diminished with time.

Chelation therapy was administered soon after their admission to the hospital. Eleven of the patients with the highest mercury levels were followed for 1-1/2 years. Blood and urine mercury concentrations were determined periodically (Figure 4). During the first two months after exposure, levels of mercury in their blood were actually within the range considered to be normal (< 50 ng/mL), and as such, did not correlate with the severity of symptoms. Concentrations of mercury in their urine were approximately 100 µg/dL and were within the range indicating significant exposure during this time. The half-lives of mercury in blood and in urine were estimated to be 45 and 56 days, respectively. Chelation therapy, tested between the third and fourth months following exposure, caused a small increase in urinary mercury, which represented only a small fraction of the total body burden of mercury.

Below-normal performance on neuropsychological tests of visual-motor skills administered upon admission to the hospital suggested a link between the mercury exposure and neurotoxic effects. Decrements in performance continued throughout the follow-up period and correlated positively with the urinary mercury levels on day 92 following exposure. The authors concluded that



At early time points, data represent the group mean ± s.d. for six patients. Day 80 and after, data represent the group mean ± s.d. for 10 patients.

Figure 4—Time Course of Mercury Excretion in Urine and Concentration in Blood After Time of Exposure (Ref. 24)

long-term, possibly irreversible neurological damage can occur as a result of acute exposure to elemental mercury and mercury vapor.

22. Effects of Lead

22.1 Bone Lead Measurements. When lead is absorbed by the body, it is initially distributed to the liver, kidney, and other organs. Because long-term storage occurs in the bone, lead levels in bone can serve as an indicator of cumulative lead exposure. In contrast, blood lead levels reflect more recent lead exposure.

A method for measuring bone lead levels using X-ray fluorescence techniques has been receiving increasing attention over the past decade. In brief, lead measurements are made by exposing the tibia (shin bone) to high-energy photons. Characteristic X-rays emitted from lead present in the bone are detected with a germanium detector and their intensity can be calibrated in units of µg lead per gram of bone mineral. Frequently in studies of lead retention in bones, measurements are taken at a second site in which the bone is more metabolically active, e.g., the calcaneus (heel) or patella (knee cap). Less metabolically active bone tissue will retain lead longer than

more metabolically active bone, and lead levels in the latter are thought to be an indicator of more recent exposures.

Gamblin (Ref. 78) determined baseline lead levels in the tibia in a nonoccupationally exposed population of 111 subjects (73 women, aged 19 to 81 years: and 38 men, aged 23 to 70 years) from southern Ontario. The bone lead content increased steadily with age in both men and women but the correlation was stronger in men than in women. Measurements from the calcaneus taken in 19 of the women showed no relationship between lead levels in the two bone types. Eight patients who had elevated blood lead levels and displayed symptoms possibly associated with lead poisoning also participated in the study. Five of these patients showed bone lead levels greater than the value expected for their age. In addition, there was a high correlation between lead levels in the calcaneus and tibia. Tibia and calcaneus lead contents were measured in an additional 27 subjects (welders, furnace rebuilders, steel workers, and gun users) 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 contents 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. The authors concluded that bone lead levels can be measured simply and safely and that these *in vivo* measurements reflect the cumulative exposure to environmental and occupational sources of lead.

Watanabe (Ref. 277) tested blood and bone lead levels in 127 volunteers from the International Brotherhood of Carpenters and Joiners (IBCJ) to determine whether potential lead exposures were associated with current or past supplementary workplace activities such as welding, exposure to lead paints, and scrap metal work. Blood lead concentrations were determined as a measure of current exposure levels and bone lead in the tibia and patella, determined by X-ray fluorescence, were taken as indicators of past exposures. Measurements were taken at a national convention of the IBCJ in Atlantic City, where most of the study participants were union representatives who had actually not worked in the trade for about 5 years. Blood lead levels were low, with a mean of 8.2 µg/dL. Bone lead levels in the tibia and patella were closely correlated with age. Age-adjusted tibia lead was positively associated ($p < 0.10$) with paint stripping, demolition, plumbing, and welding/brazing. The authors concluded that age is the most important predictor of bone lead levels among workers with intermittent exposures to lead.

22.2 Metallothionein. Metallothioneins are a class of low molecular weight proteins that strongly bind metals such as zinc, copper, cadmium and mercury. These proteins are found in most mammalian tissues. The synthesis of metallothioneins can be induced by exposure to metals. A metallothionein-like protein that binds lead was isolated from erythrocytes (red blood cells) and characterized by Church et al. (Ref. 44). The purified protein was found to bind lead when incubated *in vitro* with lead nitrate. While lead was the primary metal bound to this metallothionein, it also bound smaller quantities of copper and zinc.

Higher levels of this lead-binding metallothionein were found in erythrocytes from workers occupationally exposed to inorganic lead in a lead storage battery factory compared with controls with no known exposures to heavy metals. 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, Church et al. found that a patient with severe symptoms of lead poisoning had low concentrations of this protein compared with the welder. This finding suggests that this lead-binding metallothionein protects cells against heavy metal toxicity by sequestering circulating lead and reducing its bioavailability within the body. The investigators concluded that understanding the genetics controlling the synthesis of this protein could increase the understanding of individual susceptibility towards lead poisoning.

22.3 Treatment of Lead Poisoning. Treatment with calcium disodium ethylenediaminetetraacetate (EDTA) is generally considered to be the method of choice for lead poisoning. EDTA chelates metals and clears them from the body by excretion. Since EDTA is a nonspecific chelator of metals, it also causes excretion of essential metals such as zinc, iron, and manganese. As a result, EDTA can cause side effects such as nephrotoxicity, transitory decreases in blood pressure, and short-lasting electrocardiographic changes. EDTA does not appear to cause significant changes in blood copper levels, presumably because more than 90% of the copper in blood is normally bound to the serum protein ceruloplasm. However, in a study conducted with welders who had been hospitalized because of 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. The patients who participated in the study were 25 to 43 years of age, and were described only as lead welders. The two oldest welders had each been hospitalized previously on three separate occasions for treatment of lead poisoning. On

the day of admission to the hospital, their blood lead values ranged from 350 to 950 µg/liter. Lead values in urine collected over 24 hours after treatment with EDTA ranged from 637 to 5970 µg.

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. Five of his coworkers developed lead poisoning on the same job. The patient experienced progressive symptoms typical of lead poisoning (abdominal pain, nausea, joint and muscle pain, headaches, dizziness, visual problems, and difficulty concentrating). He was removed from the job when his blood lead level was measured at 109 µg/dL. Only the symptoms of abdominal pain and nausea resolved over several weeks. Two years later, his blood lead level was only minimally elevated but neuropsychologic tests showed short-term memory loss and other symptoms attributed to lead poisoning. He was treated with EDTA for five consecutive days. Lead excretion was greatest on the first day (555 µg) and declined rapidly thereafter. Following chelation therapy, his headaches lessened and neuropsychologic test results showed moderate improvement.

22.4 Paget's Disease. Paget's disease is a chronic, often debilitating condition in which bone resorption is increased, followed by increased, disorganized bone formation. The cause of Paget's disease is unknown and various factors such as inflammation, vascular abnormalities, genetic predisposition, endocrine imbalance, viruses, and environmental exposures have been suggested. Based on findings of possible significant exposures to lead in patients with Paget's disease, Spencer et al. (Ref. 242) postulated that this bone-seeking, toxic heavy metal is a major factor in the etiology of Paget's disease. To test this hypothesis, they examined 32 patients, aged 29 to 77 years, with Paget's disease. Diagnosis of Paget's disease was confirmed by skeletal X-ray findings, and elevated serum alkaline-phosphatase levels. Detailed occupational histories demonstrated that lead exposure was a common feature among all of the patients studied. Six of the patients were printers who had been exposed to lead pigments, seven had used lead-based paints in their work as house painters, six were automobile repairmen who had exposures to leaded gasoline, five were solderers, welders or plumbers, and the rest had other occupations which exposed them to lead. The duration of the lead exposure ranged from 2 to 49 years. The authors stated that a detailed epidemiological study of lifelong occupational and environmental histories of Paget's disease patients should be conducted to confirm or refute their hypothesis that lead is an important factor in the development of this bone-damaging disease.

23. Antioxidants

Some components of welding emissions, such as ozone and oxides of nitrogen may cause injury by acting as oxidants in biological systems. After taking up particles by phagocytosis, macrophages become activated and release the oxidants, peroxide and superoxide. While these oxidants may play a role in the natural defenses of the body against microorganisms, they can also cause tissue damage. In their work with laboratory rats (see Subsection 29, Antioxidants), Geleskul et al. (Refs. 82–85) found that intratracheally instilled welding fumes can induce peroxidation of lipids in the lungs and liver. These oxidative changes can be inhibited by administration of antioxidants such as Vitamins A, C and E (Refs. 79 and 80). Cellular and extracellular antioxidants, such as the enzymes superoxide dismutase, catalase, and glutathione peroxidase, exist naturally in the body and afford some protection to the tissues against the damaging effects of oxidants.

Mongiat et al. (Ref. 178) examined whether chronic exposure to welding fumes and gases affects the levels of superoxide dismutase, catalase, glutathione peroxidase, and reduced glutathione in erythrocytes or the serum concentrations of ceruloplasmin, a serum protein with antioxidant activity. Fifty-four electric arc welders were included in the study. Sixteen of the welders performed SMAW of mild and stainless steel and 38 welders performed GMAW of mild steel. Controls consisted of 45 healthy men with no known occupational exposure to oxidants. About half of the welders and controls were smokers.

The levels of the antioxidants tested in erythrocytes did not differ between welders and controls. However, serum ceruloplasmin levels were significantly elevated in smoking welders compared with nonsmoking welders and smoking or nonsmoking controls. The increase was greater in shielded metal arc welders than in gas metal arc welders. No correlations were noted between the ceruloplasmin levels and the duration of welding exposure or the number of cigarettes smoked. The authors noted that ceruloplasmin is also present in the lungs, where it is an important antioxidant. They conjectured that the high serum ceruloplasmin levels in smoking welders may represent an adaptive mechanism against the oxidants in welding fumes and cigarette smoke.

24. Biological Monitoring

24.1 Barium. Inhaled or ingested soluble barium salts are readily absorbed and can interfere with transport of

signals in the central nervous system, resulting in muscle contraction. Symptoms of barium exposure include cramps, diarrhea, headache, dizziness, profuse sweating and salivation. Long-term exposure can cause anaemia, weight loss, osteoporosis, tremors in the extremities, hypertension, and damage to the liver, spleen, and kidneys. More extreme exposures cause diminished muscle reflexes, speech disturbances, paralysis, and cardiac arrhythmias (Ref. 291).

Acid-soluble barium (Ba) salts, such as barium carbonate ($BaCO_3$) and barium fluoride (BaF_2) are used in the coating of some covered electrodes and may be used in the flux of self-shielded flux cored electrodes. Zschiesche et al. (Refs. 291 and 292) compared the breathing zone concentrations and the concentration of barium in plasma and in spot urine samples (i.e., urine samples collected during a single voiding) from 18 welders using barium-containing flux cored or covered electrodes under controlled conditions for 1 week. The welders who participated in the study were divided into three groups; eight performed SMAW without a local exhaust system, five performed FCAW without a local exhaust system, and five performed FCAW with a local exhaust system.

In the absence of local ventilation, many of the breathing zone measurements exceeded the TLVs for total welding fumes of 5 mg/m^3 and for soluble barium of 0.5 mg/m^3. Median fume concentrations were 13.2 mg/m^3 with SMAW and 12.3 mg/m^3 with FCAW. The median barium concentrations were 4.4 mg/m^3 and 2.0 mg/m^3, respectively. The use of welding guns with built-in extraction systems reduced the breathing zone concentrations of fume and barium to below the TLV.

Urine and blood samples were collected from each welder before and after every workshift during the 1-week study period. With SMAW, the highest urinary barium levels were measured at the end of the shift on Wednesday, the third day of the study. Median urine levels were 101.7 µg/L at that time (90% of urine samples collected from the study subjects during the week before the study, were below 20 µg/L). With FCAW, urinary barium concentrations increased in post-shift samples throughout the week and reached a maximum after the work shift on Friday, at which time the median barium concentrations in urine were 113.1 µg/L without ventilation and 44.3 µg/L with ventilation. With both SMAW and FCAW, barium concentrations in plasma were highest on Friday. The correlation between external and internal exposures was best for after-shift plasma barium concentrations ($r = 0.63$). While the association between external exposures and post-shift urine specimens was significant, the correlation was considerably weaker ($r = 0.44$) than that for plasma. 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. The investigators concluded that adherence to the TLV for soluble barium compounds is an appropriate preventive measure with a great degree of safety. Zschiesche and Schaller (Ref. 291) noted that there is a wide overlap in the barium concentrations in plasma and urine between persons with low occupational barium exposures and those with no occupational barium exposures. In addition, the large inter- and intra-individual variations between external barium exposures and barium concentrations in plasma and urine indicate that the barium content of biological fluids may best be used to demonstrate changes which may occur in barium exposure over a course of time or to monitor group exposures to barium.

24.2 Cadmium. A question that frequently arises when using urine measurements to monitor exposures to environmental chemicals is whether spot urine samples are as reliable as urine samples pooled over a longer period of time (e.g., 12 or 24 hours). The dilution of solutes in urine can vary widely throughout the day, depending, in large part, on fluid consumption. Because these variations in concentration normalize over a longer time period, spot samples may be less reliable indicators of exposures than pooled samples. To account for variations in solute dilution in spot samples, some investigators routinely adjust concentrations of test substances in urine to that of creatinine, a natural substance which tends to be excreted at a constant rate throughout the day. Concentrations of test substances can also be adjusted to specific gravity or total urinary solutes.

Trevisan et al. (Ref. 262) tested whether adjusting for either creatinine or for specific gravity increases the accuracy of measurements of cadmium concentrations in spot urine samples as compared with pooled urine samples. Urine samples were collected once a week for 3 weeks from 25 cadmium-exposed welders (22 females and 3 males) with an average exposure duration to cadmium of 4.6 years in jewelry factories. Cadmium, creatinine, and specific gravity were measured in pooled 12-hour urine samples and in spot samples collected immediately afterward.

The measured concentrations of urinary cadmium were fairly consistent from week to week over the 3-week test period. Urinary cadmium concentrations adjusted for creatine were lower than nonadjusted values or values adjusted for specific gravity. Values in spot samples were generally higher than those in the 12-hour pooled samples. Adjustment for urinary creatinine improved the correlation between concentrations measured in spot samples and in pooled samples. The authors con-

cluded that spot samples are suitable for biological monitoring of cadmium exposure when they are adjusted for creatinine. Adjustment for specific gravity appeared to be of no benefit as it did not improve the correlation between cadmium measurements in spot urine samples and in pooled samples.

The importance of adjusting the concentration of urinary cadmium to creatinine levels was also noted by Perret et al. (Ref. 204) who studied cadmium excretion by 15 precious-metal foundry workers. In addition, these investigators found that levels of urinary cadmium fluctuate throughout the day, tending to be highest in the morning and lowest in the evening. They recommended that urine samples for biological monitoring should be routinely collected in the evening, when cadmium excretion is least variable.

24.3 Chromium. The relationship between environmental workplace exposures and concentrations of nickel and chromium in blood, serum, and urine from shielded metal arc welders of stainless steel was studied by Stridsklev et al. (Ref. 249). Forty welders (38 males and 2 females) from seven different workplaces were monitored for 1 to 5 consecutive workdays. The working conditions and ventilation varied considerably from place to place.

Chromium and nickel levels in urine and plasma were close to, or below, the detection limits in nonexposed office workers who served as referents. Mean concentrations of chromium in whole blood, plasma, and urine were higher in the welders than in the referents. The total chromium concentration in blood and plasma generally increased during the workday but not over the workweek. Significant correlations were found between the levels of total chromium measured in blood, plasma and urine. The concentrations of total chromium and Cr(VI) in the workplace air were significantly correlated with the total chromium in the blood and urine. Smokers had higher levels of chromium in their blood and urine than did nonsmokers at equivalent concentrations of chromium in air. These results indicated that urine samples collected after the work shift are useful for routine monitoring of chromium in stainless steel welders. However, this did not appear to be the case with nickel. Changes in blood and urinary nickel concentrations during the workday were minimal and inconsistent. Nickel concentrations in air did not correlate with those in the blood and urine. This finding is in agreement with conclusions of other investigators (Refs. 1, 3, 288 and 289).

In a companion study, Stridsklev et al. (Ref. 250) monitored chromium and nickel levels in urine and blood collected for one workweek from 14 welders performing GTAW of stainless steel. Three of these welders also had bystander exposures from SMAW of a high-nickel alloy performed by other welders in the same work area. Iron, nickel, total chromium, and soluble Cr(VI) were determined in personal air samples and in area samples collected throughout the workweek for the eleven welders who had no extraneous exposures. Blood and urine were collected the Friday before the study. Urine was collected before and after each work shift during the week of the study, and blood samples were collected before and after the work shift on days 1, 3 and 5 of the study.

Cr(VI), total chromium, and nickel were below the detection limit in most of the air samples. When detectable, chromium and nickel were generally below 10 $\mu g/m^3$. In the 11 welders who worked in shops where only GTAW was used, blood concentrations of chromium and nickel ranged from below the detection levels to 1.0 µg/L. Urinary concentrations were below 2.0 µg/g creatinine and 8.5 µg/g creatinine for Cr and Ni, respectively. The levels of chromium and nickel did not increase with time during the workweek. None of these values differed significantly from those found in 19 office workers who served as controls. Blood concentrations of nickel and chromium also were not significantly different from controls among the three welders who worked in the same room where SMAW was performed. However, slight, but significant elevations in concentrations of total Cr in urine were observed in these welders. Based on the findings that nickel and chromium concentrations were not elevated in biological fluids from the eleven workers with no bystander-exposures to other processes, Stridsklev et al. concluded that biological monitoring is inappropriate for gas tungsten arc welders of stainless steel.

24.4 Cobalt. White and Dyne (Ref. 280) conducted a large-scale biological monitoring program for cobalt exposure in which 780 urine samples were collected over a 3-year period from about 400 persons exposed to cobalt while employed in the following occupations: chemical manufacture of cobalt powders, salt and pigments; hard metal manufacturing processes (mixing, pressing, furnace operation and post-sinter grinding operations); hard metal machining and finishing (grinding and sharpening of hard metal tools); and other metal working activities such as welding and prosthesis manufacture using cobalt-containing metals and alloys. Urine samples were collected once from each participant at the end of the shift toward the end of the week.

Median urinary cobalt concentrations and 90th percentiles for each work category are shown in Table 7. Excessive absorption of cobalt was demonstrated in the chemical-manufacturing industry where large quantities of cobalt powders and salts were handled. Urinary cobalt levels were markedly lower in workers involved with hard metal manufacturing, finishing, and machining. Cobalt-alloy workers and welders had the lowest urinary

Table 7
Median and 90th Percentile Values for Urinary Cobalt Levels in the Four Work Categories Examined by White and Dyne

Work Group	Urine Cobalt Median Value (nmol/mmol creatinine)	90th Percentile (nmol/mmol creatinine)
Chemical manufacture	93.0	486
Hard metal manufacture	19.0	107
Hard metal finishing	17.0	80
Other metal working	<3.0	42

Data from White and Dyne, Ref. 280.

cobalt levels, which the investigators attributed to good workplace hygiene practices.

The relationship between urinary cobalt concentrations and environmental cobalt levels was examined by Ferri et al. (Ref. 70) in a study with five oxyacetylene braze welders and three gas metal arc welders of stellite, an alloy containing 28% chromium, 59% cobalt, and smaller quantities of carbon, tungsten and vanadium. Workplace exposures to cobalt were determined from breathing zone samples collected over an entire work shift, and urinary cobalt was determined in samples collected at the beginning and end of the work shift.

Breathing-zone cobalt concentrations were much lower during oxyacetylene-braze welding than during GMAW (Table 8). This was probably due to the lower temperatures associated with oxyacetylene welding which are below the evaporation point of cobalt. The mean concentration of cobalt in the breathing zone of gas metal arc welders exceeded the TLV of 50 $\mu g/m^3$, and their urinary cobalt levels were markedly higher than those of oxyacetylene braze welders. Urinary excretion of cobalt by oxyacetylene-braze welders did not change significantly during the workshift, but cobalt concentrations in urine from gas metal arc welders doubled during the work shift. Urine samples were collected every other day for a full week from two of the gas metal arc welders. For each of these welders, the urinary cobalt content increased during the day and the cobalt concentration was higher in before-shift urine samples collected on Friday than in before-shift samples collected the preceding Monday, indicating a cumulative increase in cobalt levels through the workweek. The first of these welders, an experienced gas metal arc welder of stellite, had higher urinary cobalt levels than the second welder, who had only occasionally performed GMAW of stellite. This suggested that cobalt may accumulate in workers with continuous exposures to airborne levels greater than the TLV. Using the end-of-shift urinary data obtained with the two gas metal arc welders, a mean urinary concentration of 31 $\mu g/L$ was found to be equivalent to the TLV of 50 $\mu g/m^3$. When the data from the two welders were considered separately, a better correlation was obtained. The biologi-

Table 8
Breathing Zone Cobalt Levels and Cobalt in Urine Sampled at the Beginning (BS) and at the End (ES) of the Work Shift. Results Expressed as Mean (S.D.)

Process	No. of Samples	Co in Air ($\mu g/m^3$)	Co in Urine BS ($\mu g/L$)	Co in Urine ES ($\mu g/L$)
Oxyacetylene braze welding	5	3.7 (2.3)	6.8 (12.0)	6.0 (8.9)
GMAW	7	161.2 (1.5)	69.3 (44.7)	142.4 (95.6)

Data from Ferri et al., Ref. 70.

cal equivalent values were about 50 µg/L for heavy past exposure and 20 µg/L for occasional past exposure. While the number of welders examined in this study was small, Ferri et al. concluded that past exposures may interfere with the utility of urinary cobalt concentrations for biological monitoring of cobalt exposures.

24.5 Lead. A survey of blood lead concentrations in construction workers was conducted in the State of Maryland by Sokas et al. (Refs. 240 and 241). The study participants were 264 active or retired members of local ironworkers unions and local labor unions who were not known to be performing work associated with lead exposure at the time the survey was conducted. Sixty-six of the participants were laborers and 198 were ironworkers. Two of the subjects were female. Blood pressure readings were measured at the same time blood samples were taken for lead analysis.

The mean blood lead concentration of the entire cohort was 8 µg/dL (median = 7 µg/dL; range = 0 to 30 µg/dL). A survey cited by the authors found that the geometric mean for the U.S. population was 2.8 µg/dL. Blood lead concentrations were slightly, but significantly ($p = 0.01$) higher in subjects who had ever burned paint and metal and who had welded outdoors (8.56 µg/dL) compared with subjects who had participated in none of these activities (6.82 µg/dL). Blood lead levels were higher in the 58 workers who had been in workplace lead-monitoring programs (9.69 µg/dL; p=.004). Blood lead concentrations were not significantly correlated with blood pressure for the cohort as a whole, but lead levels were positively associated with blood pressure for African-American subjects. In general, the construction workers examined in this study had blood lead levels not much higher than those found in the general population. The authors attributed this finding, in part, to stringent state regulations. Unlike the OSHA lead standard, which did not cover construction workers at the time of the study, construction workers have been included in the Maryland lead standard since 1984. This standard provides for biological monitoring, medical surveillance and medical removal to protect construction workers from excess exposure to lead.

24.6 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. Reference values for manganese in blood and urine were determined in samples collected from nonoccupationally exposed persons employed at the Finnish Institute of Occupational Safety and Health. Midday spot urine samples were collected from 58 men and 96 women. Manganese levels were determined in serum and blood collected from 29 men and 36 women. The blood and serum levels of manganese in the control population were significantly lower in men than in women but there was no gender difference in urinary manganese concentrations. Blood manganese levels in men tended to decrease with age. Smoking had no effect on manganese levels in blood.

Blood and spot urine specimens were collected at midday from ten of the fifteen participating welders. The levels of manganese in blood and urine were significantly higher in the welders than in the reference population. The mean levels of manganese in urine of welders and non-welders were 19.5 nmol/L and 5.7 nmol/L, respectively, and those of manganese in blood were 0.3 µmol/L and 0.1 µmol/L, respectively. The upper 97.5% limits for manganese in urine and blood in the reference population were 38 nmol/L and 0.38 µmol/L, respectively, showing an overlap between occupationally exposed and nonexposed subjects.

More extensive studies were conducted for a full workweek with the five remaining welders. During this time, the subjects used covered electrodes that contained 2% to 3% manganese and 20% calcium fluoride in the covering to weld stainless steel which contained less than 1% manganese. Samples of fumes were collected behind the face shield throughout the week. The fumes contained, on average, 3% manganese but the breathing zone concentrations of the total dust collected from individual welders varied considerably (range = 3.4 to 19.2 mg/m^3) even though the work performed was similar. This was attributed to differences in work habits.

Spot urine samples were collected at the beginning and end of the work shift on each weekday but Wednesday; 24-hour urine samples were collected between 7 AM on Wednesday to 7 AM on Thursday. There was a good correlation between the concentration of fluoride in urine and air. However, urinary manganese levels did not correlate well with airborne manganese levels. For two welders, manganese in afternoon urine specimens correlated well with morning air concentrations. However, the correlation was minimal for the remaining three welders. Standardization of urine flow with specific gravity or creatinine did not improve the correlation. 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. These results corroborated an earlier report by Zschiesche et al. (Ref. 293) who found a poor correlation between manganese in air and in blood and urine samples from shielded metal arc welders of stainless steel containing about 0.8% manganese.

24.7 Mercury. 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 dismounting and assembling mercury-contaminated equipment in a chloralkali plant. The work required about 3 days for completion, and the workers' exposure time varied between 20 to 45 hours. Workplace area mercury levels ranged from 10 to 400 μg/m^3. Air sampling measurements taken in the breathing zones of two of the subjects showed mercury levels between 130 and 200 μg/m^3. Only two of the subjects used respiratory protection. Blood samples were collected for 4 to 6 months and urine specimens were collected for 4 months to 3 years after the exposure. Mercury levels in blood declined rapidly during the first few weeks following exposure and then declined much more slowly, thereafter. Blood mercury levels showed half-lives of 3.1 days for the initial fast phase of decline and 18 days for the slow phase (Figure 5). Mercury concentrations declined more rapidly in plasma than in erythrocytes. Urinary mercury levels reached a maximum 2 to 3 weeks after exposure. The median half-life of mercury in urine was 40 days. Based on the poor correlation between environmental mercury concentrations and urinary and blood mercury levels, the investigators did not advise the use of biological monitoring for intermittent mercury exposures.

24.8 Plutonium. Exposure of workers to plutonium-239 (Pu-239) at a nuclear reactor fuel reprocessing facility at Tarapur, India, is routinely monitored by determining radioactivity levels in urine (Ref. 107). Radioactivity in feces is also determined after suspected accidental inhalation of plutonium. The case of a 44-year-old male welder whose exposure to the alpha-emitter Pu-239 was detected by routine biological monitoring was described by Hedge et al. (Ref. 107). The initial urine sample contained 0.12 Bq Pu-239. When *in vivo* determinations of radioactivity in the lungs indicated a possible Pu-239 lung burden of more than 500 Bq, he was given a course of chelation therapy which caused a 10- to 25-fold increase in urinary excretion of Pu-239. At 201 days after exposure, the Pu-239 excretion rate was reduced to 0.009 Bq/day. Chelation therapy did not alter fecal excretion of Pu-239. Fecal Pu-239 excretion was biexponential characterized by half-lives of 2 days and 60 days (Figure 6). The authors concluded that fecal excretion data can be used to estimate initial Pu-239 lung burdens following inhalation exposure.

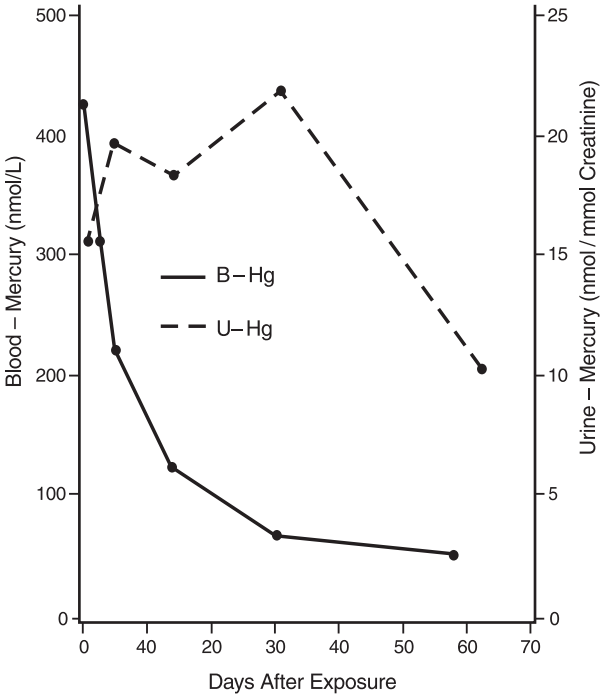


Figure 5—Mercury Concentrations in Whole Blood (B-Hg) and Urine (U-Hg) in a Worker After 3 Days of Exposure to Metallic Mercury Vapor at a Chloralkali Plant (Ref. 13)

25. Biomarkers

25.1 Genotoxicity. Biomarkers, in contrast to biological monitoring procedures, are not generally used for quanti-

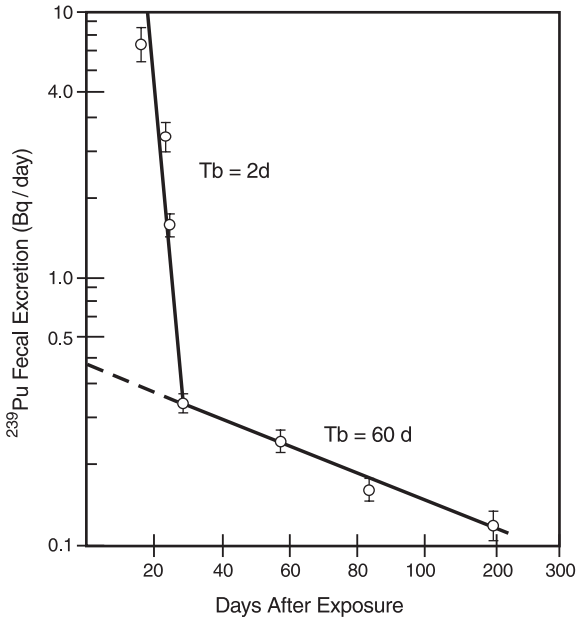


Figure 6—Fecal Excretion of ^{239}Pu by a Welder Exposed to Plutonium (Ref. 107)

tation of exposure but rather to demonstrate whether or not exposure to occupational or environmental pollutants has occurred over time. While, ideally, biomarkers reflect exposure to specific substances, alterations of macromolecules that may be related to exposures to an array of genotoxic or carcinogenic chemicals are frequently used as biomarkers. Demonstrable chromosomal damage is direct evidence of exposure. A variety of techniques is available for measurement of genotoxic effects in blood cells collected from exposed workers. Sister chromatid exchange (SCE) and chromosomal aberrations are widely used markers of genetic damage. SCE is defined as the reciprocal interchange of DNA between chromatids. SCEs are relatively easy to detect and are a sensitive indicator of low levels of DNA damage. However, their health consequences are unknown. Chromosomal aberrations are more related to mutagenic events and may be better predictors of potential adverse health effects of chemical exposures than are SCEs (Ref. 264). Unscheduled DNA synthesis (UDS) has received less attention as a biomarker of occupational exposure to DNA-damaging agents. UDS assays detect DNA synthesis during a phase of the cell cycle in which DNA synthesis does not normally occur. Like SCE, UDS reflects repair of damage to DNA that may have resulted from environmental exposures. SCEs, UDS, and chromosomal aberrations may occur in cells throughout the body but, in part because of ease of collection, peripheral blood lymphocytes are most frequently used to assay for these chromosomal changes.

Knudsen et al. (Ref. 149) investigated the frequency of SCE, chromosomal aberrations, and UDS in lymphocytes obtained from stainless steel welders. The study population consisted of 127 male welders from 15 Danish workplaces. SMAW and GTAW of stainless steel were the predominant welding processes used. The 80 controls worked at various jobs at the same plants and had not welded or ground stainless steel for at least 6 months.

Breathing zone samples were collected for a full work shift, spot urine samples were collected after the work shift, and blood samples were collected the next morning. The mean concentrations of total dust, chromium and nickel in the breathing zone air, and of chromium in urine and serum were significantly higher for welders than for the controls. Shielded metal arc welders had higher mean concentrations of chromium in urine and serum than did gas tungsten arc welders. The levels of nickel in serum did not differ between welders and controls. Also, the mutagenic activity in urine, as determined with the Salmonella/Ames assay, was the same in welders and controls.

A higher frequency of chromosomal aberrations in peripheral lymphocytes was observed in stainless steel welders than in non-welders but the frequency of SCE was lower in welders. The difference in SCE frequency became significant only when nonsmoking welders were compared with nonsmoking controls. Similarly, the frequency of UDS did not differ between welders and nonwelders unless only nonsmokers were considered. Among nonsmokers, the frequency of UDS was significantly lower in welders than in controls.

Jelmert et al. (Ref. 131) also examined the integrity of chromosomes in peripheral lymphocytes from welders performing SMAW of stainless steel. Welders (one woman and 41 men) from different companies and shipyards were studied. Exposures of 32 of the welders were monitored during the work shift using personal air samplers mounted on the collar outside the welding helmet for 4 to 5 consecutive days. Blood samples were collected from all of the participants at the end of the workweek. Airborne concentrations of chromium, but not of nickel, were significantly correlated with concentrations in blood and urine. A small, significant increase in chromatid breaks and in the number of cells with chromosomal aberrations was noted in lymphocytes from the stainless steel welders. This difference was more notable when nonsmoking welders were compared with nonsmoking controls. Studies with less-experienced welders indicated that a positive correlation between chromosomal aberrations and welding appeared only after welding stainless steel for at least 1 year. The frequency of SCE was the same in welders and controls. The mean number of SCE for smokers was elevated compared with nonsmokers but, in contrast to the findings of Knudsen (Ref. 149), there were no differences in the frequency of SCE between nonsmoking welders and nonsmoking controls.

Phagocytosis of inhaled particles by macrophages and neutrophils (a form of white blood cell) is accompanied by a “respiratory burst” during which the strong oxidants superoxide and hydrogen peroxide are released. The release of oxidants from white blood cells is an essential phase of the inflammatory process. The intensity of this reaction is dependent on the quantity of inhaled particles and their chemical and physical properties. While the release of oxidants plays an important role in the destruction of foreign bodies such as bacteria, oxidants can also contribute to pathological processes such as emphysema or bronchitis. In addition, oxidants can react with macromolecules, such as lipids, proteins, and DNA. Reaction with DNA can cause the oxidation of nucleotides or bases. (DNA is a polymer composed of four chemically distinct nucleotides, also referred to as bases. The order in which DNA bases are incorporated into DNA determines the genetic code.) Oxidized bases are cleaved from the DNA by repair processes and released into the blood stream.

Frenkel et al. (Ref. 77) investigated whether oxidized DNA bases can serve as biomarkers of exposure to cadmium, nickel, or welding fumes. In earlier work, these investigators found that people suffering from various inflammatory diseases, such as lupus, psoriasis, and immune complex or neoplastic disease, have circulating antibodies that bind to oxidized DNA bases. The levels of these antibodies declined following treatment with antiinflammatory drugs. Recognizing that inhaled metal particles can elicit an inflammatory response, Frenkel et al. hypothesized that the presence of antibodies to oxidized DNA bases in the blood stream of exposed workers could signal exposure to inflammatory metal particles.

To test this hypothesis, they examined blood collected from 31 workers exposed to cadmium and nickel at a battery factory in Poland and from 27 arc welders from Delaware, U.S.A., who were exposed to welding fumes containing manganese, nickel, and chromium during their work on railroad tracks. Oxidation of DNA was measured by the presence in the blood of antibodies to 5-hydroxymethyl-uracil (HMdU), a specific, oxidized DNA base. A positive correlation was found between the level of exposure and the titers of antibodies to HMdU in the blood of the battery factory workers. However, there was only a nonsignificant increase in the concentration of antibodies to HMdU in the welders compared with eleven non-exposed workers who served as controls. The investigators noted that they did not know if any of the welders were taking anti-inflammatory medications which could well have decreased their antibody titers. They were apparently unable to obtain detailed medical information for all of the study participants in this preliminary work.

25.2 DNA-Protein Cross-Links. Nickel and chromium exposure can cause proteins to bind covalently to DNA. While reversible binding of specific proteins to a small fraction of the DNA is essential to cellular function, aberrant nonspecific covalent bonds between DNA and proteins may interfere with gene expression or cause the deletion of important sections of the genome during DNA replication. Some investigators have postulated that DNA-protein cross-links may play a role in the mechanism of chromium carcinogenicity.

Zhitkovich and Costa (Ref. 286) developed a rapid method for detecting DNA-protein cross-links in cells. The method relies on the selective precipitation of DNA containing cross-linked proteins by treatment with sodium dodecyl sulfate and potassium chloride. In a pilot study using this method, Costa et al. (Refs. 50–52 and 259) examined the frequency of DNA-protein cross-links in peripheral white blood cells collected from 21 welders and from 26 unexposed controls. The welders had worked for at least 6 months on railroad tracks or in railroad track shops and they frequently used SMAW with high Mn-Ni-Cr electrodes. The levels of chromium and nickel in blood samples from the welders were barely detectable and did not differ significantly from those of non-welding controls.

DNA-protein cross-links were reported in terms of the percent DNA with covalently bound protein. A significant increase in DNA-protein cross-links was observed in welders ($P = 0.01$); mean cross-link values were 1.85% among the welders and 1.17% among the controls. All of the excess DNA-protein cross-links were found in five of the 21 welders (Figure 7). The excess DNA-protein cross-links in these welders suggested exposure to cross-linking agents. The authors indicated that the results of this analysis must be cautiously interpreted because of the small sample size and the possible presence of confounding factors such as smoking and dietary factors. The results of this work corroborated the results

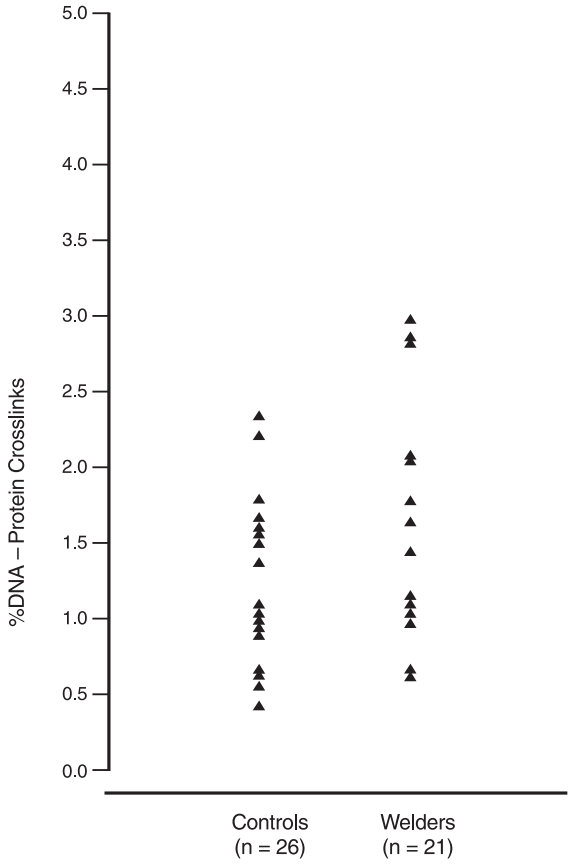


Figure 7—DNA-Protein Cross-Links Values Among Railroad Welders and Controls (Ref. 51)

reported by Popp et al. (Refs. 207 and 208) who, using alkaline filter elution, found an increased rate of DNA cross-linking in lymphocytes collected from chromium- and nickel-exposed welders.

25.3 Hair and Nails. Gorban et al. (Ref. 93) measured the manganese content of hair from 228 steel welders who used electrodes with a high-manganese content. Breathing zone fume concentrations and hair samples were analyzed in 1977 and, again, in 1984. Breathing zone welding fume samples contained 12% to 30% Mn. At both times, the manganese content of hair samples collected from welders correlated positively with breathing zone welding fume concentrations. Manganese concentrations in hair from welders exposed to fume concentrations less than 5 mg/m^3 were two to four times greater than the Mn content in hair taken from controls with no occupational exposures to Mn. Welders exposed to fume concentrations greater than 15 mg/m^3 had seven to eight times more Mn in hair samples than did controls. Some of the welders who stopped welding after 1977 contributed hair samples for the second-half of the study in 1984. At this time, the Mn content of their hair was indistinguishable from that of the controls. The authors concluded that the measurement of Mn in hair is a more reliable indicator of body burden than are urine or blood samples. However, this may be questionable since it is not possible to determine how much of the Mn content of hair resulted from deposition on the hair from the environment and how much of it actually resulted from internal absorption of environmental Mn. The authors also stated that the incidence of functional abnormalities in the central nervous system and in the cerebral blood vessels of the Mn-exposed welders correlated with the Mn content in their hair samples. However, no descriptions of "central nervous system functional abnormalities" were given, there was no statistical analysis of data, and there was no information about how data concerning medical symptoms were collected.

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. Levels in samples collected from industrial workers were compared with published data on levels of elements in hair in the general population in the U.S.A., and with levels in nails in the general Canadian population. While most of the trace elements measured varied similarly in hair and nail samples, gold, bromine, cadmium and rubidium were present in higher concentrations in hair than in nail samples, which the investigators attributed to a greater external absorption from the environment. 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 of the trace elements measured were higher in nail samples obtained from workers compared with the general Canadian population.

Section Three
Investigations in Animals and Cell Cultures

26. Effects of Electromagnetic Fields on Fetal Development

Kowalczuk et al. (Ref. 152) examined the effects of exposure to electromagnetic fields (EMFs) on fetal development in mice. The intensity of the EMFs to which mice were exposed was comparable to those that could be encountered by induction furnace workers and arc welders. A total of 90 pregnant mice were exposed to a 50-Hz (hertz) sinusoidal magnetic field at 20 mT during the first 17 days of gestation. Exposure to EMFs had no affect on survival rates of fetuses and did not cause external, internal, or skeletal abnormalities. The only significant findings were that fetuses exposed *in utero* to EMFs were slightly longer and heavier at birth, and had fewer external abnormalities compared with fetuses from the 86 unexposed control mice. Kowalczuk concluded that exposure to levels of EMF tested in this study does not adversely affect fetal development in mice. He cited a number of related studies in which similar observations were made in laboratory rats and mice.

27. Fertility

In 1990, Ernst (Ref. 66) reported that treatment of rats with Cr(VI), but not Cr(III), for 5 consecutive days by intraperitoneal injection caused testicular atrophy and a marked reduction in the epididymal sperm count. These effects were dose-related and were minimal at the lowest dose tested (1 mg Cr(VI)/kg body weight). This work was repeated in a more recent study (Ref. 67) using a lower dose of Cr(VI) and increasing the treatment from 1 week to 8 weeks. In the repeated study, the reversibility of the effects of Cr(VI) on the male reproductive system was investigated by examining the animals 8 weeks after the last treatment, giving them time to recover from the effects of Cr(VI). The protocol used was as follows. Male rats were treated 5 days per week for 8 weeks with 0.5 mg Na_2CrO_4 per kg body weight. Sperm quality and serum concentrations of testosterone, LH, and FSH were tested in half the rats at the end of the 8-week treatment period. To determine if the effects of Cr(VI) on sperm

quality or serum hormones are reversible, these parameters were examined in the remaining rats after an 8-week treatment-free recovery period.

Statistically significant reductions in the number of motile sperm and in serum testosterone levels were seen in rats examined immediately after the 8-week exposure period. Concentrations of LH and FSH were significantly increased in serum and a small, nonsignificant reduction in total sperm count was observed (Table 9). All the sperm parameters were normal at the end of the 8-week recovery period. The only effect that remained to be seen at this time was a small reduction in the LH concentration. Thus, the effects of Cr(VI) on the male rat reproductive system appear to be reversible.

28. Metal Fume Fever

The effects of exposure to ultrafine zinc oxide particles at a concentration equal to the ACGIH TLV of 5 mg/m^3 were tested in rabbits, rats, guinea pigs, and humans by Gordon et al. (Ref. 94). As discussed above (Subsection 11, Metal Fume Fever), each of four human volunteers who were exposed for 2 hours to 5 mg/m^3 ultrafine zinc oxide developed one or more symptoms of metal fume fever within 6 to 10 hours after exposure. Similar exposure levels caused acute inflammatory changes in the lungs of guinea pigs and rats, but not rabbits. Animals were exposed by inhalation for up to 3 hours to 2.5 mg/m^3 or 5 mg/m^3 ultrafine zinc oxide particles. BAL fluid was collected and examined for signs of inflammation at 0, 4, and 24 hours after exposure. Phagocytosis of latex beads, used as a measure of macrophage function, was depressed in guinea pigs, but not in rabbits. Indicators of acute inflammatory changes in the lung, including total cell count, lactate dehydrogenase, beta-glucuronidase, and protein content, were elevated in BAL fluid from guinea pigs and rats, but not rabbits. The changes were greatest at 24 hours after exposure. The observed pulmonary inflammatory response was directly related to the quantity of inhaled zinc oxide particles that was retained in the respiratory tract. The fraction of the inhaled dose retained in the lungs was 20%, 12%, and 5% for guinea pigs, rats, and rabbits, respectively. Thus, the differences in response among the three species were attributed to the fraction of the inhaled material that was retained in the lungs. The investigators concluded that acute inflammatory changes can occur in the mammalian lung after exposure to zinc oxide aerosols at levels equivalent to the current TLV.

29. Antioxidants

Since 1987, Geleskul and collaborators have been conducting a series of studies in which they used peroxidation of lipids in rat tissues to compare the relative toxicities of fumes generated by different welding rods (Refs. 81–86). The general protocol used in these studies was to introduce welding fumes into rat lungs by intratracheal instillation and, after an appropriate waiting period, to measure the peroxidation of lipids in liver or lung tissue. Techniques used to quantify lipid peroxidation included measurement of mitochondrial concentrations of

Table 9
Epididymal Sperm Parameters and Sexual Hormones in Rats Treated with Cr(VI) for 8 Weeks

Treatment	Sperm Count ($\times 10^6$)	Sperm Motility (%)	Morphology (% Abnormal)	Testosterone (nmol/L)	FSH (IU/L)	LH (IU/L)
Examination at end of 8-week treatment period						
Exposed rats	600 ± 34	30 ± 6[a]	6.8 ± 1.1	3.5 ± 1.30[b]	0.27 ± 0.15[a]	1.15 ± 0.35[b]
Control rats	623 ± 24	63 ± 5	6.7 ± 1.2	5.0 ± 1.00	0.17 ± 0.12	1.05 ± 0.26
Examination after 8-week recovery period						
Exposed rats	639 ± 26	61 ± 5	7.2 ± 1.1	4.9 ± 0.99	0.17 ± 0.10	1.00 ± 48[b]
Control rats	641 ± 29	58 ± 6	7.0 ± 2.0	5.1 ± 1.05	0.16 ± 0.20	1.39 ± 0.30

a. Statistically different from control animals ($p < 0.001$)
b. Statistically different from control animals ($p < 0.05$)

Data from Ernst, Ref. 67.

malondialdehyde and glutathione/glutathione reductase. The effects of intratracheally instilled fumes on the chemiluminescent properties of macrophages isolated from the peritoneum or peripheral blood were also tested in some of these investigations.

In a new phase of this work, Geleskul et al. (Ref. 80) investigated whether treatment of rats with antioxidants could inhibit the lipid peroxidation resulting from intratracheally instilled welding fumes. The welding fumes used in the study contained 5.3% Mn, 11.4% Si, 5.3% K, 11% Na, 11% F, 8.4% Ca, and 30% Fe; the conditions under which the fume was produced were not described. The welding fumes were dispersed in physiological saline, and a single dose of 50 mg was instilled into the lungs of each rat. Lipid peroxidation was measured by chemiluminescence in peripheral white blood cells and by the malondialdehyde content of liver mitochondria.

Antioxidants (vitamin A, vitamin E, vitamin C, and quercetin) were administered by stomach tube or by injection using two different regimens. In the first regimen, antioxidants were administered 2 days before, and 3 days after instillation of welding fumes. This treatment completely inhibited the lipid peroxidation produced by administration of welding fumes alone.

In the second regimen, rats were treated repeatedly with antioxidants (4 days per month for 4 months) starting about 1 week after the administration of welding fumes. In rats treated with welding fumes alone, malondialdehyde doubled by 14 days after treatment, tripled by 30 days, and stayed at that level for the remaining 3 months of the study. In rats treated with antioxidants after instillation of welding fumes, malondialdehyde levels increased in parallel with that in rats given welding fumes alone for the first 14 days but they declined steeply by the end of 30 days. Malondialdehyde levels in these animals were the same as those in untreated control rats by the end of the 4-month study period. Similar results were obtained when chemiluminescence in peripheral white blood cells was used as the measure of lipid peroxidation.

A second study conducted by these investigators (Ref. 79) used a similar design but followed treated animals for 6 months instead of 4 months after treatment. The composition of the welding fume (11.8% Mn, 1.9% Si, 7.5% K, 15.3% Na, 9.6% F, 1.4% Ca, and 30% Fe) was slightly different from that used in the previous work. The protective effect of the antioxidants vitamin A, vitamin C, and vitamin E against the formation of malondialdehyde in the liver was similar to that seen in the previous work. Changes in the activity of the liver enzymes superoxide dismutase, glutathione peroxidase, and glutathione reductase, which play a role in protecting tissues from the effects of oxidants, were less dramatic in animals treated with antioxidants. The investigators concluded that antioxidants can be used effectively to prevent or to treat lipid peroxidation resulting from inhalation of welding fumes.

30. *In Vitro* Studies

Feren et al. (Ref. 69) examined the toxicity and potential carcinogenicity of nickel subsulfide and particles produced by SMAW of stainless steel in an *in vitro* system using cultured primary rat tracheal epithelial cells. Normally, cultured cells multiply until a monolayer of cells fills the bottom of the tissue culture dish in which they are placed. In the presence of carcinogens or potential carcinogens, the cells can become "transformed" to form colonies in which cells divide uncontrollably and pile up on top of each other. Cell transformation assays may be used as a screening test to determine whether chemicals are carcinogenic. However, many substances which are not carcinogenic can cause cell transformation. Thus, to prove that a transforming substance is carcinogenic, it is necessary to demonstrate that transformed cell colonies form tumors when injected into immunosuppressed mice.

Feren et al. (Ref. 69) found that welding fume particles were more cytotoxic to cultured epithelial cells than were nickel subsulfide particles. The authors surmised that the greater destruction of cells by welding fume particles was due to the release of soluble chromates. As expected, nickel subsulfide, a known carcinogen, was a potent transforming agent. The extent of cell transformation caused by potassium chromate ($K_2Cr_2O_7$) or welding fume particles was about one-fourth that produced by nickel subsulfide. Experiments were not conducted with immunosuppressed mice to determine whether or not the transformed cells were tumorigenic.

The effect of welding fumes on guinea pig alveolar macrophages was studied by Otmane et al. (Ref. 194). Macrophages, obtained by bronchoalveolar lavage, were incubated *in vitro* for 3 days with fume particulates generated by SMAW or GMAW of stainless steel or GMAW of cast iron using a pure-nickel welding electrode. The fume particulates were taken up by the macrophages after addition to the cells. The appearance of beta-glucuronidase in the cell medium was used as a measure of cytotoxicity. Cell death was greater in cells treated with welding fumes than in control cells. Fumes from SMAW were more cytotoxic than fumes from GMAW, which the authors suggested was due to the higher soluble Cr(VI) content of the SMAW fumes. The macrophages were examined for ultrastructural modifications by electron microscopy. The primary ultrastructural modification of the alveolar macrophages was an increase in the number of microvilli with respect to the control cells.

31. Gene Expression

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. When the synthesis of a protein is induced, the section of the genome or DNA that contains the genetic code for that particular protein is copied in the form of messenger RNA (mRNA). The mRNA, which carries the instructions for the amino acid sequence of the protein, is then transported from the cell nucleus into the cytoplasm where it directs the synthesis of the induced protein. The induction of mRNA is referred to as gene expression.

Three investigations determined quantities of specific mRNAs in lung tissues or cells as a measure of the induction of the synthesis of specific proteins by welding fumes. The first study was conducted by Wiethege (Ref. 282), who investigated the induction of the cytokine TNF in alveolar macrophages by welding fumes and other particles.

Macrophages activated by the ingestion or phagocytosis of particles, release hydrolytic enzymes and other substances or mediators that initiate the inflammatory process essential to the early phases of the immune response. Cytokines and other mediators released from macrophages 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. The concentration of one such mediator, TNF, was used as a measure of the degree of activation of alveolar macrophages in the study by Wiethege (Ref. 282). Molecular biology techniques were used to detect expression of TNF mRNA by *in vitro* hybridization with specific DNA probes. An increase in the number of copies of TNF mRNA in the macrophage would signify activation of the genetic machinery for producing TNF.

Rat alveolar macrophages were obtained by lung lavage and incubated *in vitro* with quartz dust, welding fumes, and crocidolite asbestos. TNF mRNA was expressed at the highest rate in macrophages stimulated by quartz dust, followed by those stimulated by welding dust, and then crocidolite. In all cases, the expression of TNF mRNA reached a peak 4 hours after exposure to the test particles and was elevated for only a short period (Figure 8). Because the levels of TNF mRNA varied widely with the three particle types, Wiethege concluded that different respirable dusts to which workers may be exposed vary with respect to the potential lung damage that may be mediated by activated alveolar macrophages.

A similar study by Ossege et al. (Ref. 193) compared the induction of synthesis of the protein alpha-2-macroglobulin by crocidolite, quartz, or welding fumes in isolated rat alveolar macrophages. Activated macrophages release proteases (enzymes which digest proteins) that can damage the extracellular matrix. Alpha-2-macroglobulin is a protease-inhibitor, which is also synthesized by macrophages and can protect the lung tissue from the action of proteases. The investigators noted that all three types of particles stimulated the expression of alpha-2-

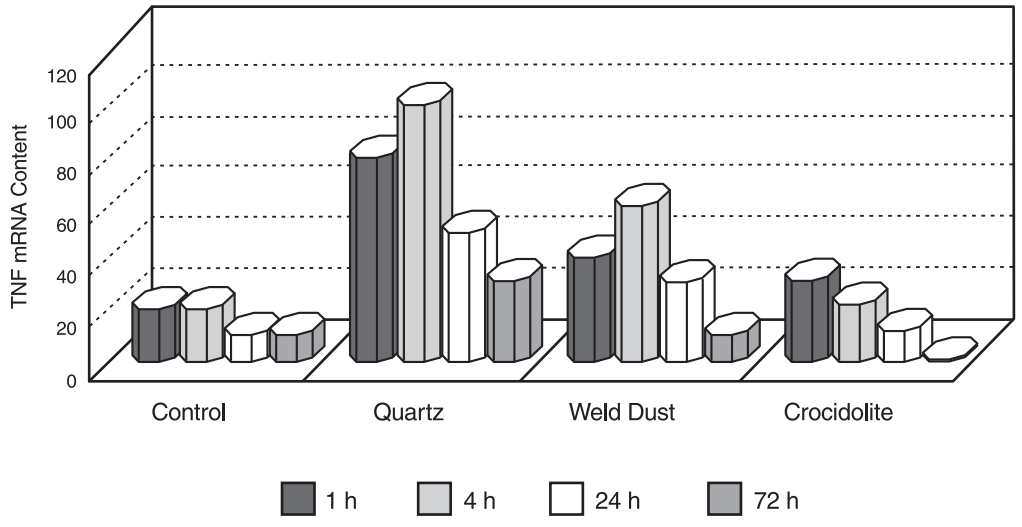


Figure 8—Induction of Tumor Necrosis Factor (TNF) mRNA in Alveolar Macrophages by Quartz, Welding Dust, and Crocidolite Asbestos (Ref. 282)

macroglobulin-mRNA. Only minor differences in the levels of induction of alpha-2-macroglobulin by crocidolite, quartz or welding fumes were noted.

In the third study, Cosma et al. (Ref. 49) investigated the potential for welding exposures to induce the expression of two proteins, metallothionein and heme oxygenase, in lung tissue. Heme oxygenase is normally involved in the breakdown of heme into bile pigments but it is also thought to be involved in the natural defenses of the body by scavenging free radicals. Metallothioneins are proteins that strongly bind metals such as zinc, copper, cadmium, and mercury (see Subsection 22.2, Metallothionein). The sequestration of metals by metallothionein is thought to protect cells from the effects of toxic metals. The synthesis of both metallothioneins and heme oxygenase can be induced by metals. The goal of this study was to determine the potential for occupationally relevant levels of welding fume components to cause the expression of genes known to be induced by metals.

Rats were exposed by inhalation for 3 hours to 1, 2.5, or 5 mg/m^3 zinc oxide fumes (count median diameter 0.06 µm) or for 6 hours to 0.5 or 1.0 ppm ozone. Lung tissue was obtained at various times after exposure, and levels of the mRNA specific for metallothionein and heme oxygenase were determined. Zinc oxide fume caused about an 8-fold increase in lung metallothionein mRNA at the two highest doses tested and caused 8-, 5-, and 11-fold increases in heme oxygenase-specific mRNA at doses of 1, 2.5, and 5 mg/m^3 zinc oxide, respectively ($p < 0.05$). The levels of mRNA specific for both proteins were greatest in lung tissue examined immediately after exposure and declined to control levels by 24 hours postexposure (Figure 9). In contrast, ozone caused no increase in the mRNA for either protein.

These results demonstrated that levels of zinc oxide equal to or less than the TLV of 5 mg/m^3 can induce the synthesis of proteins involved in the acute respiratory response to foreign particles. The authors concluded that it is not clear whether these responses reflect pulmonary injury or adaptive responses in exposed tissue.

In summary, metal oxide particles can induce alveolar macrophages to synthesize: (1) the cytokine TNF (Ref. 282), which has been postulated by Blanc et al. (Ref. 22) to be a mediator of metal fume fever; and (2) alpha-2-macroglobulin (Ref. 193), which inhibits proteases that are released from activated macrophages. Zinc oxide particles (Ref. 49) can induce the synthesis in lung tissues of: (1) heme oxygenase which can scavenge free radicals released from activated macrophages; and (2) metallothionein, which sequesters metals and may thereby protect cells from the effects of toxic metals. Thus, while the phagocytosis of metal oxide particles may induce macrophages to produce substances that may injure the lung (e.g., proteases, oxidants), the same particles can also induce macrophages or lung tissue to synthesize proteins that protect against these potentially injurious substances.

If the levels of metallothionein increase in the lung with successive exposures to metal oxide particles, then, as suggested by Cosma et al. (Ref. 49), the sequestration of metal particles could become more efficient with successive exposures. Such a phenomenon has been

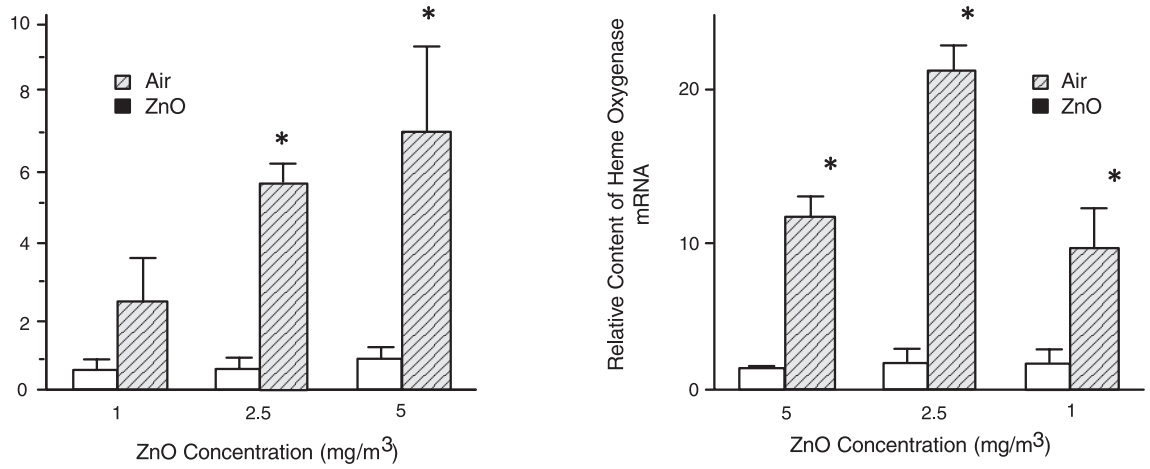


Figure 9—Expression of Metallothionein and Heme Oxygenase Genes in Rat Lung Tissue 3 Hours After Inhalation of Zinc Oxide (ZnO) (Ref. 49)

demonstrated for cadmium exposures by Squibb et al. (Ref. 244). Extending this idea, one can surmise that the tolerance to welding fumes that develops through the workweek is related to increasing levels of metallothionein in the lungs. Assuming further that metallothionein decreases to normal levels during a weekend break from welding exposures, the protective effects of metallothionein could be lost during that time, which would explain why metal fume fever most frequently occurs on Mondays.

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