



Effects of Welding on Health, XI



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, XI

Prepared for
AWS Safety and Health Committee

Research performed by
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Abstract

This literature review, with 171 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, XI*, 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, Index—I through X*, each covering approximately 18 months to two years. Conclusions based on this review and recommendations for further research are presented in the introductory portions of the report. Referenced materials are available from:

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Glossary*

ACGIH	American Conference of Governmental Industrial Hygienists
Atopy	Positive response to skin prick tests with common allergens
BALF	Bronchoalveolar lavage fluid
CI	Confidence Interval
Cr(III)	Trivalent chromium
Cr(VI)	Hexavalent chromium
CT	Computed tomography
dB	Decibel
Dyspnea	Difficulty breathing; shortness of breath
EDTA	Ethylenediaminetetraacetate
EMF	Electromagnetic field
FFR	Fume formation rate
GMAW	Gas metal arc welding
HRCT	High resolution computed tomography
Hz	Hertz
IgA	Immunoglobulin A
IgE	Immunoglobulin E
IL-1	Interleukin-1
IL-4	Interleukin-4
IL-6	Interleukin-6
IR	Infrared
Leukocyte	White blood cell
MRI	Magnetic resonance imaging
μ T	Microtesla
n	Number of subjects
NIOSH	National Institute for Occupational Safety and Health
nm	Nanometer
OR	Odds ratio
OSHA	Occupational Safety and Health Administration
OPMR	Proportional mortality ratio
PCB	Polychlorinated biphenyls
PEL	Permissible exposure limit
RR	Relative risk
SIR	Standardized incidence 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
UV	Ultraviolet
UVA	UV wavelengths of 315–400 nm
UVB	UV wavelengths of 280–315 nm
UVC	UV wavelengths of 100–280 nm

*Abbreviations for commonly used pulmonary function tests are found in Table 5.

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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*. Ten volumes have been published to date; the first covered data published before 1978, while the remainder covered 1 to 3 year periods between 1978 and December, 1994. The current report includes information published between January 1995 and December, 1996. 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 Section 1 of this volume are studies of the characteristics of welding emissions that may have an impact on the control technologies necessary to protect the welder. 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 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 bronchitis continues to be explored. Investigations of the association of asthma with welding increase in number as the prevalence of both occupational and non-occupational asthma increases worldwide in industrialized countries. 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. Current studies do not indicate that stainless steel welders are at a greater risk for developing lung cancer than are mild steel welders. However, studies in laboratory rats showed that stainless steel welding fumes are cleared more slowly from the lungs than are mild steel welding fumes. Studies from Ukraine continue to focus on the deposition and potential deleterious effects of iron in organs other than the lung. While, as in the past, no studies focused on health effects of welding in women due to their small representation in the trade, two articles addressed the question of ergonomic, safety, and sociological stresses faced by female construction workers.

Executive Summary

Health and Safety

The importance of proper training was demonstrated in a case report by Arend et al. (Ref. 10) who described a case of arc welding maculopathy in a 26-year-old male welding student who experienced blurred vision in both eyes immediately after leaving a 4-hour arc welding course. Having been improperly instructed about choice of protective lenses, he chose to use lenses that afforded him the greatest visibility of the weld area but provided inadequate protection against visible light radiation. Examination 12 hours later revealed oval white lesions in the foveas of both eyes with a blind spot in each eye and small loss of visual acuity. Little improvement was seen upon examination 1 year later. Special needs for training were also expressed by women interviewed by Goldenhar (Ref. 58). Unlike men, who are frequently exposed in their childhood to the use of, and precautions associated with shop tools and mechanical equipment, women rarely have this exposure as youths and may need more training than men when entering construction trades to ensure that they are familiar with hazards associated with welding equipment and other tools and machinery.

Burns. Serious burns have resulted from sparks produced during resistance welding. Excessive welding current results in the formation of free molten metal which can be ejected with high velocity from the weld site as metal sparks. These sparks can penetrate deeply into the skin and may require surgical excision. Four such injuries were described in 1993 (Ref. 2) and 1994 (Ref. 57) and, more recently, Shanahan described (Ref. 129) five cases which occurred within a one-month period at a motor vehicle factory. Three of the injuries occurred through leather gloves and two involved injuries of unprotected skin. Surgical excision of the metal particles was required for each of these injuries, and skin grafting was necessary in all but one.

Effects on the Respiratory Tract

Pulmonary Function Changes in Welders. Beckett et al. (Ref. 16) found that respiratory symptoms increased and a small decline in pulmonary function occurred dur-

ing the course of a single workshift among welders in a British shipyard. No changes in pulmonary function were seen, however, in welders in the same shipyard over a 3-year period. No deleterious effects of welding on pulmonary function were seen in studies of Canadian welders and cutters (Ref. 126) and French welders and metalworkers (Sobascek, Ref. 135) but, in the latter study, welders of stainless steel had a significantly increased incidence of shortness of breath on exertion.

Other investigators found small, but significant, decrements in pulmonary function in populations of welders. Chinn et al. (Ref. 32) found significantly diminished lung function in shipyard welders who had remained in the same job for 7 years. They also observed some beneficial effects on pulmonary function in the welders who had used local exhaust ventilation. A small, but significant, deficit in lung function was found among welders compared with other workers who participated in state-mandated tests in Austria (Refs. 118 and 167). Ironworkers who used welding and oxygas cutting equipment had increased respiratory symptoms and decreased lung function that were significantly related to their length of employment, but the effects of welding, asbestos exposure, and smoking could not be separated (Ref. 124). Welding of stellite, an alloy of cobalt and chromium, was significantly related to a decline in pulmonary function (Ref. 80). Chronic bronchitis was found to be elevated among groups of welders in Turkey (Ref. 109) and Serbia (Ref. 73).

Occupational Asthma. Beach et al. (Refs. 13 and 14) found significant increases in airways responsiveness that were related to years of employment as a welder and may be predictive of development of asthma. Toren et al. (Ref. 148) found that male welders under age 45 were significantly more likely to report having bronchial asthma than the general population in Sweden (Ref. 148). In other studies of various design, welders were included in groups of industrial occupations along with solderers and electronic assemblers (Refs. 52, 84, and 98). In all of these studies, increased risks for asthma were found in the occupational group that included welders but, because the exposures of welders can differ considerably from other occupations included in the group,

it is difficult to separate out the effects of welding. Three cases of asthma were confirmed by clinical investigations (Refs. 81, 149, and 153) to be caused by occupational exposure to welding fumes.

Cancer

Lung Cancer. Two studies conducted by the same investigators using different epidemiologic approaches (Refs. 62 and 90) showed significantly increased risks for lung cancer in a group of Danish men employed in welding, grinding, and other metal trades between 1964 and 1984. The retrospective study conducted by Hansen et al. (Ref. 62) showed a significantly greater incidence of lung cancer among members of the Danish cohort who were identified as having been welders or having been employed by a welding company. The increased risk was of the same magnitude among welders and nonwelding metal workers. The case-referent study conducted by Lauritsen et al. (Ref. 90), showed that, of the men who had died between 1968 and 1985, those who had ever welded had a 70% greater risk of dying from lung cancer.

Danielsen et al. (Ref. 38) conducted a historical prospective cohort study of the incidence of cancer among Norwegian boiler welders employed between 1953 and 1992. They observed a 33% increase in the incidence of lung cancer, but it was not statistically significant. The relative risk for lung cancer associated with stainless steel welding was close to unity and was much lower than that for the entire cohort of welders. Using pooled data from 36 studies, Moulin (Ref. 100) estimated that welders had a 36% greater risk for lung cancer than the combined control populations. No differences were seen in the lung cancer risk between stainless steel and mild steel welders or between shipyard welders and nonshipyard welders.

Cancers in Organs Other than the Lung. Danielsen et al. observed a significantly increased risk of kidney cancer in the cohort of Norwegian boiler welders (Ref. 38). The association between exposure to electromagnetic fields (EMFs) and development of leukemia or brain cancer is still a matter of controversy (Ref. 147). An association between childhood nervous system cancer and paternal welding was not significant and could not be unequivocally attributed to EMF exposure (Ref. 166). Cancer of the eye was significantly associated with welding, but there was no apparent increase in the risk for ocular cancer with increasing years of exposure (Ref. 69). Welding was associated with increased, but not statistically significant risks for prostate cancer (Ref. 154), malignant lymphoma (Ref. 49) and biliary tract cancer (Ref. 34).

Health Effects Related to Duration of Welding Experience

Associations between exposures and effects are strengthened by observation of a positive dose-response relationship. If there are cumulative health effects, they would be expected to be more prevalent and more pronounced among those with longer welding experience. When detailed exposure histories and industrial hygiene measurements are unavailable, a welder's length of employment in the profession is often used as an indication of the cumulative dose from exposure to welding fumes. A positive duration-effects relationship was found by Beach et al. (Refs. 13 and 14) in a study of young shipyard welders of mild steel who, during their first 9 years in the trade, showed changes in airways reactivity. These changes, which could be signs of progression toward the development of asthma, were related to years of employment as welders. Even though a positive relationship between exposure duration and effects is observed in a study, the findings may be distorted by confounding factors. Rocskay et al. (Ref. 124) found increased radiographic abnormalities, respiratory symptoms, and deficits in lung function that were positively related to duration of employment in a group of ironworkers who performed welding and cutting, but, as the authors stated, these effects could also have been related to smoking and to exposure to asbestos. In a study by Lauritsen and Hansen (Ref. 90), lung cancer mortality was significantly associated with duration of exposure to welding fumes up to 15 years but in welders with more than 15 years experience, the odds ratios for lung cancer were not as large, and the differences between welders and nonwelders were no longer significant.

Several other investigators had less success finding relationships between years of welding and the incidence of health effects. Sobaszek et al. (Ref. 135) found a small deficit in midexpiratory flow rates associated with years of experience welding stainless steel, but there were no other duration-related effects for other populations of welders or in other lung function tests. Ozdemir (Ref. 109) found no differences in the frequency of chronic bronchitis or in lung function between groups of welders with more than or less than 20 years experience. Toren (Ref. 148) found a significantly higher incidence of self-reported asthma among welders than in the general population, but the incidence was highest among welders younger than 45 years old. Rossignol (Ref. 126) found no association of lung function with welding fume exposure except among welders older than 45, who performed better in lung function tests than did younger, less experienced welders. Holly et al. (Ref. 69) found a significantly increased risk for uveal melanoma (cancer of the eye) among welders that was unrelated to years of welding

experience. The possibility that a single severe burn to the eye may be associated with an increased risk for this cancer may explain the lack of a relationship between the risk for eye cancer and the duration of the welding experience.

The most commonly offered explanation for the scarcity of evidence for a cumulative effect of welding exposure is that workers who are affected by their working environment are prone to migrate to other employment. This is an often-cited hypothesis in the case of occupational asthma, where respiratory problems may develop before the onset of clinical asthma. Evidence in support of this phenomenon is provided by the finding of Chinn et al. (Ref. 32) that significantly more of those who were unavailable for a follow-up health assessment had reported having respiratory symptoms when examined 7 years earlier than had those who were available for the second examination. Although lung cancer is an insidious disease, Lauritsen and Hansen (Ref. 90) also cited the migration effect as an explanation for their failure to find an increased lung cancer risk related to duration of exposure past 15 years.

Claims for Compensation. Several investigators used claims for compensation from different government insurance bodies as indices for the occurrence of disabling disease among welders and other workers. When there was another basis for comparison, most of the incidence rates based on claims appeared to be seriously underestimated (Refs. 12, 28, 50, 98, and 127). A notable exception is the registry maintained by the Finnish Institute of Occupational Health. All employees are required to be insured, compensation is generous, and diagnoses of disabling disease are thorough, resulting in a relatively complete and accurate measure of the incidence of occupational diseases in Finland (Ref. 98). Two groups of investigators examined lung tissue from workers who had lung cancer. Dufresne et al. (Ref. 43) used electron and light microscopy to detect asbestos and metallic particles in lung tissue from aluminum smelter workers who had died from lung cancer or mesothelioma. Raithel et al. (Ref. 121) used atomic absorption spectroscopy to measure the nickel and chromium content of lung tissue from metal workers with cancer. The authors noted that these techniques could be used to supply evidence of exposure in support of claims for compensation.

Iron Overload Syndrome. Three studies of welders by a group of Ukrainian investigators focused on chronic iron overload syndrome (hemochromatosis). In this disorder, excessive amounts of iron are absorbed through the gut from the diet and deposited in various body organs, particularly the liver, heart, and pancreas. Early indications of hemochromatosis are elevated serum iron, transferrin-

bound iron, and serum ferritin levels. With time, iron builds up in the organs, and the ultimate effects of this condition include cirrhosis of the liver, diabetes, enlarged heart, cardiac arrhythmias, and heart failure. While hemochromatosis is most frequently caused by inherited factors, acquired forms of the disease might be associated with excessive exposure to iron.

Kucheruk and Lubianova (Ref. 88) found an association between premature aging in welders and excess levels of total iron and transferrin-bound iron in the blood. Using noninvasive biomagnetic techniques, Sosnitzky et al. (Refs. 136 and 89) obtained data suggestive of deposition of iron in the liver and heart muscle in welders with chronic respiratory ailments. These changes, as well as elevated serum iron concentrations, were found more frequently in welders with pneumoconiosis than in those with chronic bronchitis. The authors concluded that, in patients with pneumoconiosis, iron may leave the lungs through the blood stream to become deposited in the heart and liver, suggesting that a disease related to the genetically-acquired iron overloading syndrome is possible in workers chronically exposed to iron oxide fumes. They hypothesized that the accumulation of iron in the liver could have deleterious physiological manifestations such as the promotion of lipid peroxidation, an effect which has been studied extensively by Geleskul and his colleagues (Refs. 55 and 56), also in Ukraine.

Finally, Lubianova and Novichenko (Ref. 94) tested blood drawn from welders for antibodies to two tumor antigens that appear on the surface of premalignant or malignant cells. Positive reactions to these antigens were more frequent in welders with pneumoconiosis than in those with bronchitis and were more frequent among current welders than among those who had ceased welding. The authors concluded that these data show that the number of transformed, premalignant cells in the lungs is exposure-related and reversible. Increased levels of iron and transferrin in the blood were found in the welders who showed positive reactions to the tumor antigens which suggested that an increased cancer risk among welders may be associated with the accumulation of iron in susceptible organs. Further evidence cited by the authors for a role of iron in the development of cancer comes from increased levels of hepatocellular carcinoma in patients with hereditary chronic iron overload syndrome and from tissue culture studies in which cell transformation was induced by addition of iron.

Cytokines. The role in disease processes of cytokines and oxidants released from macrophages and neutrophils following phagocytosis of fume particles in the lungs continues to be a point of discussion among investigators. The cytokines tumor necrosis factor (TNF), Interleukin-1 (IL-1) and Interleukin-6 (IL-6) are important

because they are released from alveolar macrophages as they engulf foreign particles and can have both beneficial and detrimental effects on the body. They are essential to the inflammatory and immune processes because they attract white blood cells into the area of foreign particles. However, cytokines also induce the growth of fibroblasts which can eventually cause fibrosis (scar tissue) to form in the lungs. It has also been postulated by Blanc et al. (Ref. 19) that TNF is a mediator of metal fume fever.

Antonini (Refs. 8 and 9) administered particles generated by welding mild and stainless steel to rats by intratracheal instillation. They found that the stainless steel welding fumes were cleared more slowly from the lungs and induced a greater inflammatory response. Levels of the cytokines TNF and IL-1 were significantly elevated in the bronchoalveolar lavage fluid from rats treated with fumes from welding stainless steel but not mild steel.

Sjogren (Ref. 134) postulated that inhaled ultrafine particles generated by welding and by other industrial processes could be related to an elevated risk of ischemic heart disease. Interleukin 6 (IL-6), a cytokine released from macrophages and neutrophils activated by phagocytosis of particles, can stimulate the production of fibrinogen, a serum protein involved in blood clotting. The resultant increased coagulability of the blood could possibly lead to an increased risk for heart disease. Support for this hypothesis was derived from the observation of Blanc et al. (Ref. 19) that IL-6 concentrations are increased in bronchiolar lavage fluid (BALF) from welders exposed to fumes generated by welding galvanized mild steel. Hilt et al. (Ref. 65) found that grinders, but not welders, have an elevated risk for ischemic heart disease. They are currently examining blood concentrations of fibrinogen and IL-6 among welders during a work week.

Technical Summary

The Exposure

Fume Composition

Bunton (Ref. 26) found that spattering or sparking during electron-beam welding is increased by a variety of conditions, including coating the metal surface with a film of oil, punching holes in the surface along the weld, and butt welding of a rough joint. He also observed that sparks were more likely to occur at the start or finish of a weld or when welding over a previously-welded area.

Hewett (Ref. 63) found that the bulk fume densities and the specific surface areas of particles in fumes produced by GMAW were greater than those produced by SMAW. Similarly, the mass distribution of particles was shifted towards the smaller particle sizes in fumes from GMAW compared with SMAW. Elemental analysis showed that metals were evenly distributed throughout the range of particle sizes. Analysis of these data using established models, (Ref. 64) predicted that between 23% and 41% of the mass of the welding fumes characterized in the study would be deposited in the lungs, mainly in the alveoli. Total lung deposition was estimated to be 60% higher for GMAW fumes than for an equivalent mass of SMAW fumes, and the total surface area of the particles in the GMAW fumes was calculated to be nearly three times that of the SMAW fumes.

Perrault et al. (Ref. 115) found that 16% of the particles in fumes from SMAW of stainless steel contained chromium and that chromium levels were highest in particles with aerodynamic diameters less than 1 μm . Analysis of the fumes collected on the stages of an Andersen cascade impactor showed that the concentration of Cr(VI) was greater than that of Cr(III) in all particle size fractions.

Dennis and Mortazavi (Ref. 41) showed that addition of 1% zinc to the core of a welding electrode increased the fume formation rate but produced a significant reduction of Cr(VI) in fumes generated by GMAW at a welding voltage of 18 V. These investigators also found (Ref. 40) that ozone levels could be markedly reduced during GMAW by using a modified welding gun that produces twin concentric shield gas shrouds with an internal shield

gas of argon containing 5% CO₂ and 2% O₂ and an outer shield gas of either argon with 300 ppm nitric oxide or trace quantities of ethylene.

Analytical Methods

Nickel. Butler et al. (Ref. 27) examined the methods recommended in the United Kingdom for analysis of nickel in dusts collected from workplace air. Five different procedures for dissolution of different types of dust samples were evaluated, and all were found to meet the requirements for sample detection of the newly-established British exposure limits for nickel.

Polychlorinated Biphenyls. Using a method he developed for extraction and analysis of polychlorinated biphenyls (PCBs) in paint chip samples, Welsh (Ref. 163) showed that three of six samples of railroad car paint scrapings had PCB concentrations in excess of the Canadian environmental standard of 50 ppm. Welsh concluded that there could be health risks to welders and other workers performing repairs on such materials.

Workplace Exposures

Vinzents et al. (Ref. 158) examined fumes generated by welding aluminum and found that the median measurements of total and inhalable dust concentrations were nearly identical. However, there was 1.4 times more aluminum in the inhalable fraction of the fume than in the unfractionated fume, indicating that industrial hygiene measurements of the aluminum content in the total fume might underestimate the quantity of aluminum that could be inhaled.

Hori et al. (Ref. 71) measured concentrations and size distributions of welding fume samples collected at 20 workplaces in Japan. Average fume concentrations were 11.3 mg/m³ in personal samples, 0.4 mg/m³ in general area samples, and 46.8 mg/m³ in source samples. The authors concluded that neither general area nor point source sampling is a reliable substitute for personal monitoring.

Karlsen et al. (Ref. 79) collected fume samples from the breathing zones of welders performing SMAW of

Inconel alloy which contained about 60% nickel; the Inconel electrodes contained about 20% chromium. The mean nickel concentrations in fumes from SMAW of Inconel were greater than those from SMAW of stainless steel while the mean concentrations of total Cr, Cr(VI), Fe, and Mn were marginally lower in the fumes from Inconel.

Liu et al. (Ref. 92) measured breathing zone lead concentrations and particle size distributions in welding fumes generated by high voltage welding during lead battery manufacturing. The mean concentration of lead in the welding fumes was 26 $\mu\text{g}/\text{m}^3$ but particles greater than 10 μm in diameter accounted for 71% of the mass of the samples.

Linnainmaa et al. (Ref. 91) characterized particles produced during welding, brazing, and grinding of stellite (an alloy of cobalt, chromium, and tungsten) and hard metal (an alloy of tungsten carbide and cobalt) in Finnish tool manufacturing companies and blade repair shops. The particles produced during welding of stellite contained mainly cobalt and iron, while the principal components of particles produced by grinding the stellite tips were chromium and cobalt. Particles collected during brazing and grinding of hard metal contained cobalt, tungsten and iron. These results differed from those of Teschke et al. (Ref. 144) who found that chromium, but not cobalt, was a constituent of fume generated by welding stellite tips onto saw blades.

Electromagnetic Radiation

Chou and Cullen (Ref. 33) assessed exposures to ultraviolet (UV) radiation at an automotive assembly plant. They found that UV irradiance levels produced while spot welding with electrodes operating at 10 to 15 kA and 10 to 20 V were several orders of magnitude below recommended safety limits for industrial exposure.

Knuschke and Barth (Ref. 83) measured the daily doses of UV radiation received by workers exposed to arc welding in a European railway repair station who had complained of eye problems. The welders' daily UV exposures were 7.5 to 70 times the German occupational limit for UV exposure and the daily exposures of the welding assistants was 4 to 12 times the limit.

Klebanov (Ref. 82) measured the UV light output of various welding techniques in a factory in the Republic of Belarus. For air plasma cutting, the levels of UVB and UVC were close to the industrial standard. Radiation levels produced by electric arc welding and plasma deposition were consistently higher than the industrial standard. Radiation from oxyfuel gas welding was several orders of magnitude lower than that from arc welding.

Electromagnetic Fields

Exposure to Electromagnetic Fields. Floderus et al. (Ref. 51) assessed Swedish workplace exposures to extremely low frequency electromagnetic fields. Of the 100 major occupations studied, welders had the highest exposure.

Interaction with Cardiac Defibrillators. Fetter et al. (Ref. 48) measured the strength of magnetic fields generated by welding equipment in a study of their effects on the functioning of cardioverter-defibrillators. Since none of the welding equipment tested produced measurable interference with the implantable defibrillators, the authors concluded that it was safe for welders with these devices to return to work as welders if they undertook common-sense safety precautions, including periodic individual evaluation of the interaction of EMFs generated in the workplace with the device in the patient. Embil and Geddes (Ref. 45) and Pinski and Trohman (Ref. 116) were in accord with this conclusion.

Hygiene and Work Practice

Protective Gear and Equipment. Liu et al. (Ref. 93) measured metal fume concentrations inside and outside the welding helmet in the personal breathing zones of 20 welders performing electric arc welding on galvanized mild steel using a cellulose-covered electrode. The mean ratio of inside-to-outside iron concentrations was 0.9; the median ratio was 0.96 which indicated that the welding helmet provides ineffective attenuation of exposure to welding fumes. Using a respiratory plethysmograph and a mass spectrometer, Stromberg (Ref. 141) developed a method for measuring the volume of CO_2 in the dead space of a welding visor and the fraction of CO_2 in the inspired air of welders wearing visors. The mean inspired CO_2 concentrations for subjects wearing the visor were higher than the TLV.

Traumatic Injuries. Zwerling et al. (Ref. 171) conducted a survey of traumatic injuries seen in nine hospitals in rural Iowa and found that construction workers visited the emergency rooms 2.7 times more frequently than did workers in nonconstruction occupations, and that work-related injuries were 4.7 times more frequent among the construction workers. Contact with hot tar among roofers and "flash burns" to the eyes of welders were the leading causes of work-related burns to construction workers in the study population.

Electrocution. Approximately 5% of work-related fatalities have been attributed to electrical injury. Risk factors include use of electric power tools with wet or perspiration-covered hands, use of improperly grounded portable arc welding equipment, and working with power tools in

wet environments (Ref. 111). Peng and Shikui (Ref. 113) described seven deaths from electrocution by low voltages from AC and DC electric welding machines. All of the incidents occurred during the summer in closed environments with high temperature and high humidity.

Hazards Faced by Tradeswomen. Goldenhar and Sweeney (Ref. 58) determined that one of the greatest workplace hazards unique to women is the lack of protective workplace gloves and clothing designed for females. Poorly fitting protective clothing, such as gloves, can increase the risk of accidents. Tools designed for use by the average man may be unwieldy for most women and may increase the exertion required for a given task, causing ergonomic stress.

Safety. Jarvinen et al. (Ref. 76) described a design procedure, using three-dimensional computer simulation models of the work environment, to optimize safety and ergonomic considerations in automated manufacturing systems. They described a case study in which this procedure was used to develop safety procedures for a welding robot system for GMAW of long beams and automobile parts.

Hazard Surveys. Tharr (Ref. 145) summarized the hazards to workers found by the Occupational Safety and Health Administration during health and safety consultation visits to small industrial sites in Colorado. At all 132 sites visited for safety inspections in 1990, welding and brazing accounted for an average of 10.4 identified hazards per 100 workers. Other types of hazards were much more prevalent. Hale et al. (Ref. 60) described the National Occupational Health Survey of Mining, which has been conducted in 491 selected U.S. mines by the National Institute for Occupational Safety and Health. Worksite data have been collected in seven exposure categories: generic chemicals, trade name products, physical agents, musculoskeletal overload conditions, welding processes, grinding metals, and bulk settled dust.

Effects of Welding on Human Health

Respiratory Tract

Pulmonary Function. Beckett et al. (Ref. 16) studied changes in respiratory function and symptoms in shipyard welders across a work shift and over a 3-year period. Respiratory symptoms increased during a welding day and decreased during a day off from work, and there was a small, but significant, decrease in one measure of maximum expiratory flow during a work day. No

changes in lung function or airways reactivity were seen among the welders during the 3-year observation period. Chinn et al. (Ref. 32) assessed the contribution of improved respiratory protection measures in a 7-year study of young shipyard welders and caulker/burners who had access to exhaust ventilation throughout their careers. Lung function was significantly diminished among welders and caulker/burners who remained at the shipyard for the entire 7-year study period. Expiratory flow rates had deteriorated among welders who admitted to not using exhaust ventilation, and this did not improve over an average of four years after leaving the shipyard. Among the welders who had used exhaust ventilation, there was a decline in the peak expiratory flow rate, but this was reversible. In a companion study, Chinn et al. (Ref. 30) showed that increases in relative body mass were significantly correlated with decrements in lung function, and should be taken into account when studying changes in lung function over time.

Rossignol et al. (Ref. 126) found no decrease in lung function in a group of Canadian welders and cutters over a 5-year period. Sobaszek (Ref. 135) found no significant differences in lung function between mild steel welders and stainless steel welders or between welders and non-welders from eight French factories. There was a significant increase in dyspnea among the stainless steel welders. Wolf et al. (Ref. 167) and Pirich et al. (Ref. 117) found a small, but significant decline in maximum expiratory flow rate among welders compared with other workers who were required to undergo lung function tests in Austria. Rocskay (Ref. 124) examined asbestos-exposed ironworkers who had used welding and oxygas cutting equipment in Michigan. Increased respiratory symptoms and declines in lung function were significantly related to duration of experience as ironworkers, but the effects of asbestos, welding and cutting, and smoking could not be separated. Kennedy et al. (Ref. 80) found a significant decline in lung function among welders who spent more than 10% of their time welding stellite, an alloy of cobalt and chromium.

Ozdemir et al. (Ref. 109) compared respiratory symptoms and lung function in male welders and clerks in Turkey. Chronic bronchitis was significantly more frequent among welders and among smokers. Ignjatovic et al. (Ref. 73) also found an elevated risk for chronic bronchitis among welders in Serbia.

Occupational Asthma. Beach et al. (Refs. 13 and 14) studied subclinical changes that may be predictive of asthma in welders and other workers who had been employed for up to 9 years in a British shipyard. Among mild steel welders, there was a significant increase in airways responsiveness related to years of experience, compared with a group of office workers. Changes in airways

responsiveness were related to total fume concentrations but not to concentrations of nickel or chromium. Based on their results, the authors predicted that about 1% of mild steel welders would develop symptomatic asthma after 5 years of work.

Kogevinas (Ref. 84) found increased risk for asthma among an occupational group that included welders, solderers, and electronic assemblers when asthma was characterized by wheezing or whistling in the lungs, by shortness of breath, or by currently being medicated for asthma. Meredith and Norman (Ref. 98) evaluated registries for tracking the incidence of occupational asthma in four countries. They concluded that, with the exception of the registry of occupational asthma maintained by the Finnish Institute of Occupational Health, the registries under-reported the number of cases. Flodin et al. (Ref. 52) analyzed bronchial asthma in broad categories of Swedish workers and found a significantly increased risk for bronchial asthma in the category that included welders (along with 55 other job titles) compared with the working population as a whole. In a prospective study of bronchial responsiveness, Simonsson et al. (Ref. 131) found significant lung function test decrements indicative of increased bronchial reactivity among welders. Using self-reported cases of occupational asthma in Sweden, Toren (Ref. 148) found that male welders age 20–44 were significantly more likely than the remainder of the working male population to have the disease. Devereux et al. (Ref. 42) investigated the role of dietary sodium in the development of asthma and concluded that it was unlikely to be a contributing factor to the etiology of the disease.

Khoo (Ref. 81) described a case of occupational asthma which occurred in a 36-year-old male shipyard arc welder in Singapore after three months of gas metal arc welding. Tests performed four years after symptoms were first reported confirmed the diagnosis. Torres (Ref. 149) treated a 24-year-old female welder who had developed shortness of breath, cough, and tightness in the chest after one year of exposure to solders and fluxes. Removal from the workplace caused cessation of symptoms, although she still displayed bronchial hyperresponsiveness. Vandenplas et al. (Ref. 153) examined a 21-year-old man who had developed asthma after three months experience welding mild steel. Tests in which he was exposed to welding fumes generated in a hospital clinic demonstrated that his asthmatic reactions were specifically related to the GMAW procedure.

Other Respiratory Tract Conditions. Baur (Ref. 12) reported that welders and cutters accounted for the majority of insurance claims for occupational asthma and other allergic respiratory tract conditions made by workers in the metal working industries of western Germany. Radenbach et al. (Ref. 120) summarized the results of

examinations of thirty male welders in Germany with symptoms of occupational lung disease. Welders who worked in shipyards and repair plants had the greatest incidence of symptoms and the largest decrements in lung function. Yoshida et al. (Ref. 169) found welding to be implicated in 4 of 115 cases of hypersensitivity pneumonitis that could be related to occupational exposures in Japan. Welch et al. (Ref. 162) studied former shipyard workers with rhinitis. These workers had been exposed to welding, burning, and paint fumes while working in enclosed spaces. Polyakov et al. (Ref. 118) detected signs of pulmonary hypertension in five of nine Russian welders examined.

Pneumoconiosis. Roesler (Ref. 125) described the progression of siderosis (accumulation of ferric oxide particles in the lungs) in a welder who had been successfully treated for tuberculosis at age 25. By age 44, he had reduced lung capacity, and his condition was attributed to welding, but other factors, such as his tuberculosis may have contributed. Spacilova (Refs. 137 and 138) examined lung abnormalities and respiratory changes in 111 welders over an average of 10 years, during which time the number of cases of chronic bronchitis increased from 27 to 42. Akira (Ref. 1) used computed tomography to characterize the radiographic features of pneumoconioses resulting from exposure to welding fumes, hard metal, aluminum, or graphite dusts. Park et al. (Ref. 110) compared pulmonary function tests and opacities seen in chest X-rays in Korean welders and coal miners with pneumoconiosis.

Cancer

Lung Cancer. Hansen et al. (Ref. 61) studied the incidence of lung cancer in 8372 welders and other metal workers in Denmark. An increased incidence of lung cancer among all welders was not statistically significant, but nonwelding metal workers and workers identified as having ever been employed either as a welder or by a welding company had a significantly increased incidence of the disease. No link was established in this study between length of employment as a welder and risk for lung cancer. In a case-referent mortality study of the same group of metal workers, Lauritsen and Hansen (Ref. 90) observed a statistically significant increase in mortality from lung cancer among those who had ever welded. There was a positive relationship between lung cancer mortality and the duration of the welding experience for the first 15 years of exposure, but not thereafter. Exposure information in this study was obtained from spouses and coworkers of the deceased employees, and the validity of this technique was demonstrated in a study

by Hansen (Ref. 61). Danielsen et al. (Ref. 38) studied the incidence of cancer among Norwegian boiler welders, many of whom had been exposed to asbestos. An increased risk for lung cancer among the entire cohort of welders was not statistically significant. There was a statistically significant increase in the risk for kidney cancer among the welders.

Moulin (Ref. 100) analyzed 35 studies of lung cancer among welders and combined their results in a meta-analysis which showed that welders of all types have increased relative risks for lung cancer. No differences in the incidence of lung cancer were shown between shipyard welders and non-shipyard welders or between mild steel and stainless steel welders. Finkelstein (Ref. 50) used death certificate records to study associations of occupational exposures and lung cancer mortality in two Canadian cities. While he did not find an increase in lung cancer mortality among welders, he calculated that the deaths from the disease among welders far outnumbered the claims submitted for workers' compensation. Similarly, Caroyer et al. (Ref. 28) found that of the 30,000 cancers diagnosed in Belgium in 1984, 1500 were attributed to occupational exposures, but only 52 men with cancer were compensated. Raithel et al. (Ref. 121) found that concentrations of nickel and chromium were as much as 100 times higher in lung tissue samples from German metal workers who had died from lung cancer than in lung tissue from control populations. Dufresne et al. examined lung tissue from aluminum smelter workers who had died of lung cancer or mesothelioma. Plaques or fibrosis were present in all of the lung cancer cases as were asbestos fibers, fragments of silicates, and nonfibrous particles containing chromium, cobalt, and aluminum.

Cancers at Other Sites. Theegarten et al. (Ref. 146) examined lung tissue from a plumber and fitter who had died of carcinoma of the trachea. He had been exposed to asbestos, mineral fibers, and welding fumes, and iron-containing particles, and evidence of all of these materials was found in his lungs, along with fibrosis near the bronchioles. Theriault (Ref. 147) evaluated recent studies of cancers associated with electromagnetic fields (EMFs) and found evidence in support of an association between working in electrical occupations and an increased risk of both leukemia and brain cancer. The evidence implicating exposure to EMFs was inconclusive, in large part because exposures were poorly defined and inadequately measured. Wilkins and Wellage (Ref. 166) related cases of childhood cancers of the central nervous system to paternal occupation. An association between paternal occupation as a welder and risk for central nervous system tumors was not significant. In a case-control study in the western U.S., Holly et al. (Ref. 69) found that welders had a statistically increased risk, unrelated to the dura-

tion of their welding experience, for uveal melanoma, a cancer of the eye. Welders had a nonsignificantly greater risk for prostate cancer in a case-referent study conducted by van der Gulden et al. (Ref. 154) in the Netherlands. In a death certificate-based case-control study, Figgs et al. (Ref. 49) found a nonsignificantly increased risk for non-Hodgkins lymphoma among welders. Chow et al. (Ref. 34) found a nonsignificantly increased risk for biliary tract cancer among male and female workers in the category of plumbers, welders, and sheet metal workers in Shanghai, China.

Magnetopneumography and Related Techniques

Hogstedt et al. (Ref. 68) compared the quantities of magnetite in the lungs of 23 welders, as measured by magnetopneumography and by visual analysis of chest x-rays. The correlation between the results obtained using these two methods was weak and was not statistically significant. Using Superconducting Quantum Interference Detectors (SQUID), Kruty et al. (Refs. 85, 86, and 87) compared the particulate lung burdens in two groups of active arc welders in the Slovak Republic. Significantly greater quantities of magnetizable substances were found in the lungs of the welders who had worked in confined spaces than in welders who had had better working conditions. The content of magnetizable particles in the lungs was roughly proportional to the duration of the welding experience. Using noninvasive biomagnetic techniques, Sosnitzky et al. (Refs. 89 and 136) obtained data which suggested that iron can become deposited in the heart and liver of welders with pneumoconiosis.

Effects on the Ear

Mahmoud et al. (Ref. 96) measured noise levels and tested hearing thresholds among workers at a pipe factory in Libya. Age and years of exposure were significant determinants in the development of hearing loss at 2000 to 4000 Hz, but these two parameters were not independent of each other. Short-term effects of noise on hearing were studied by Mukhin (Ref. 101) in a group of Ukrainian workers engaged in rolling, press forging, and welding of electrical conduit. Average hearing thresholds rapidly increased during the workshift, and the changes were statistically significant at 1000 and 2000 Hz. Ivanovich et al. (Ref. 75) measured workplace noise and tested hearing sensitivity in 229 workers in a Bulgarian sheet metal factory and found that occupationally-induced hearing loss was greater among roller workers, furnace men, cutters, and crane workers than among fitters,

welders, and electricians. The deficits in hearing sensitivity were more closely related to age than to the duration of occupational experience. Bruhl et al. (Ref. 25) documented improvements in noise levels in a Swedish automobile plant over a 25-year period resulting from noise reduction measures.

Effects on the Eye

Zlateva (Ref. 170) found that the incidence of lens and cataracts was significantly higher for welders under age 45 than for controls in the same age range. Arc welding maculopathy was described by Arend et al. (Ref. 10) in a 26-year-old male welding student who experienced blurred vision in both eyes immediately after leaving a 4-hour arc welding course. Using data collected from five Danish hospitals between 1989–1991, Holmich et al. (Ref. 70) found that the majority of eye injuries that occurred during avocational activities were foreign-body lesions and actinic conjunctivitis that resulted from the use of drilling, welding, or grinding equipment.

Effects on the Skin

Dermatosis. Elsner (Ref. 44) described the case of a 32-year-old welder with atopic dermatitis that was exacerbated by exposure to UVC (100–280 nm) radiation. The case of a 44-year-old Japanese man with 30 years welding experience who developed Bowen's disease, a precancerous, slow growing skin disease that may become malignant, was described by Oiso (Ref. 104)

Burns. Injuries from fires, explosions, and related incidents reported to the United Kingdom Health and Safety Executive in 1992 and 1993 were summarized and reviewed by Owens and Hazeldean (Ref. 108). Of a total of 675 injuries, 20 incidents involved gas welding equipment and resulted from leaking or burst acetylene, fuel gas, or oxygen hoses. An additional 24 incidents involved burns resulting from the use of cutting and welding equipment. Five cases of serious burns from sparks produced during resistance welding that occurred within a one-month period at a motor vehicle manufacturer were described by Shanahan (Ref. 129). Surgical excision of the metal particles was required for each of these injuries and, in all but one, skin grafting was necessary.

Effects on the Nervous System

Amyotrophic Lateral Sclerosis. Vanacore et al. (Ref. 152) described the case of a 44-year-old welder who developed ALS after being employed for 13 years as a

welder, working mostly with SMAW or GMAW in confined spaces with inadequate ventilation. Strickland et al. (Ref. 140) conducted a case-control study in which 25 ALS patients who were being treated at the University of Minnesota ALS Clinic were compared with two groups of age- and sex-matched controls residing in the same geographical area. The strongest association with ALS was exposure to welding and soldering materials and working in the welding industry (OR = 5.3, CI = 0.97–26.0).

Manganese and Aluminum. Sjogren et al. (Ref. 132) administered a comprehensive battery of psychological and neurophysiological tests to groups of welders with a history of exposure to either manganese or aluminum. They concluded that neurotoxic effects had resulted from exposure to these metals.

Effects on the Musculoskeletal System

Carpal Tunnel Syndrome. Baldasseroni et al. (Ref. 11) conducted a case-control study of the prevalence of carpal tunnel syndrome among Italian workers with different job classifications. The incidence of carpal tunnel syndrome was nonsignificantly elevated in the job classification carpenters and welders. Andersson et al. (Ref. 4) described a 31-year-old right-handed man who had been employed in automobile manufacturing for 13 years. Three weeks after switching to a job that required positioning a spot welder beneath cars moving overhead, he experienced pain in both wrists and numbness in the fingers of his left hand. After six months, carpal tunnel syndrome was confirmed bilaterally and surgery was required on both hands.

Epicondylitis. Ritz (Ref. 123) examined 290 male employees of a water works in Hamburg, Germany for evidence of humeral epicondylitis ("tennis elbow"). Welders and pipefitters were considered to have high exposure because of the forceful rotation of the elbow joint that is required while they are holding and fitting heavy pipes. Comparison with the unexposed group showed that statistically significant increases in the incidence of humeral epicondylitis occurred after ten years of exposure among both current and former welders and pipefitters in the highly exposed group. Having previously worked as a welder or pipefitter for 24 years was associated with a 6.3-fold increase in the prevalence of epicondylitis. There was a positive dose-response relationship between epicondylitis and years of employment in welding and pipefitting.

Lower Back Pain. Wickstrom et al. (Ref. 164) described a video-based method for evaluation of the physical load

on the lumbar spine in welders during normal work activity. The jobs that caused the most prolonged disk compression and continuous lumbodorsal fascia strain were grinding of the weld bead and carbon-arc gouging.

Effects on the Kidney

Chromium. To determine whether there are signs of changes in kidney function in chromium-exposed welders, Bonde and Vittinghus (Ref. 23) compared the concentrations of five proteins in urine samples from 102 metal welders and 33 referents who had never welded. There was no relationship between the level of exposure to mild steel welding fumes and concentrations of urinary proteins, nor were there differences in protein excretion patterns between mild and stainless steel welders. In addition, no relationship was found between the number of years of welding experience and urinary protein levels.

End-Stage Renal Failure. In a case/control study designed to examine the role of occupational exposures in the development of chronic renal failure, Nuyts et al. (Ref. 103) found that kidney disease was significantly increased by exposure to lead, copper, chromium, tin, mercury, and welding fumes, but not to cadmium.

Effects on the Cardiovascular System

Cardiovascular Disease. Drawing upon a hypothesis developed by Seaton (Ref. 128), Sjogren (Ref. 134) postulated that ultrafine particles generated by welding and by other industrial processes could be related to an elevated risk of ischemic heart disease. Seaton's hypothesis was based on the release of mediators that stimulate the production of fibrinogen, a serum protein involved in blood clotting from leukocytes (white blood cells) responding to the deposition in the lungs of ultrafine particulate pollutants from urban air. A preliminary report by Hilt et al. (Ref. 66) indicated that welders have an elevated risk of ischemic heart disease. However, Hilt et al. (Ref. 67) later refined the statistical analysis of their data and found that grinders, but not welders, are at increased risk for cardiovascular disease.

Vibration-Induced White Finger. Ostman et al. (Ref. 107) conducted a study of 59 welders with VWF which showed that this condition does not continue to progress

following cessation of exposure to causative factors such as handheld vibrating tools and, in many cases, it may be reversible.

Effects on Reproduction

Effects on Fertility. Wu and Zhang (1996) studied the effects of exposure to manganese and welding fumes on semen quality in 63 men who had worked in manganese mining and refining, 110 shipyard welders, and 38 machine shop welders. They concluded that manganese exposure has a toxic effect on sperm production. In a review of epidemiological and experimental findings regarding occupational hazards to the male human reproductive system, Tas et al. (Ref. 142) cited thirteen studies which considered reproductive effects of welding. They cited evidence showing that exposure to cadmium and lead, two metals that may be present in welding fumes, may have reproductive effects.

Birth Defects. Blatter et al. (Ref. 20) conducted a case-control study of the association between parental occupation and spina bifida in offspring. An increased risk of producing a child with spina bifida was found for male welders, but it was not statistically significant.

Effects of Specific Metals

Effects of Manganese. Angle (Ref. 6) tested the effects of the chelator, dimercaptosuccinic acid, on blood and urine levels of manganese in two welders who had been chronically exposed to manganese and concluded that the results did not encourage further trials of this chemical.

Effects of Beryllium. Using the lymphocyte proliferation test to detect hypersensitivity to beryllium which is thought to be one of the early signs of chronic beryllium disease, Stange et al. (Ref. 139) found that adherence to the TLV may be insufficient to prevent sensitization of workers to beryllium.

Effects of Cadmium. Ando et al. (Ref. 5) described the case of a 43-year-old man who was exposed to cadmium fumes while working with silver solder in a large iron pot. When he finished the job he had nausea, followed by difficulty breathing, chills, and fever. His symptoms continued to worsen and by the fifth day following exposure, he developed pulmonary edema.

Effects of Lead. In 1991, a collaboration among the Connecticut Department of Public Health, the Connecticut Department of Transportation (DOT), and the National Institute for Occupational Safety and Health implemented a joint plan to reduce lead toxicity in bridge workers through the incorporation into state contracts of protective measures which required monitoring and reduction of lead exposures at bridge sites and monitoring blood lead levels in workers (Ref. 29). Blood lead levels were found to decrease substantially after the program was implemented in 1991. For ironworkers/welders, average blood lead levels declined steadily from 20.6 µg/dL in 1991 to 10.9 µg/dL in 1994.

Hunaiti et al. (Ref. 72) determined the concentrations of lead in blood collected from 263 men residing in northern Jordan, some of whom had jobs in which they were potentially exposed to lead. The mean blood lead concentration was highest in metal casters (41.6 µg/dL blood) followed by radiator welders (32.8 µg/dL).

General Health

In a survey of work-related health problems among automobile mechanics and workers in associated trades in a city in Nigeria, Omokhodion and Osungbade (Ref. 105) noted that musculoskeletal disorders, particularly lower back pain, were the most common work-related health problems among automobile mechanics. The incidence of dermatitis was highest in the 50 workers classified as panel beaters and welders.

Case Report

Tvedt et al. (Ref. 150) described an incident in which a 36-year-old Norwegian shipyard worker was inside a carbon steel pipe, using GMAW with an argon shielding gas. Fifteen to twenty minutes after returning to work from a break, he was found unconscious in a sitting position in the pipe. As a result of this incident he had long-lasting effects including tremors, difficulty reading and performing calculations, excessive fatigue, and reduced memory.

Biological Monitoring

Matczak et al. (Ref. 97) examined the relationship between chromium concentrations in urine from fifteen welders of a high alloy Cr-Ni stainless steel and their exposure to total chromium, Cr(VI), and Cr(III) in welding fumes. The correlation between urinary and airborne

chromium exposures was closest when the daily difference between the before and after shift urine chromium concentrations was compared with the chromium content of the fumes. It was concluded that a more precise measure of exposure to chromium can be obtained by determining the increase of urinary chromium during the workshift than by measuring it only at the end of the work shift.

Biomarkers

Genotoxicity. Jelmert et al. (Ref. 77) examined the integrity of chromosomes in peripheral lymphocytes collected from 44 stainless steel welders, of whom 23 used GTAW and 21 used GMAW. The numbers of gaps, chromatid and chromosome breaks, and cells with chromosomal aberrations were lower in welders than in referents. No differences were seen in the incidence of sister chromatid exchanges between welders and non-welders. De et al. (Ref. 39) found that the frequency of chromosomal aberrations was significantly greater in nine workers, including two welders, from a machine shop in India the metal workers than in the controls.

DNA-Protein Cross-Links. Costa et al. (Ref. 37) compared chromium concentrations in red blood cells and urine, and DNA-protein cross-links in peripheral blood lymphocytes from Bulgarian chrome platers, and subjects from the Bulgarian cities of Jambol and Burgas, which have high and low levels of air pollution, respectively. Concentrations of red blood cell chromium, but not urinary chromium, correlated strongly with the levels of cross-links in lymphocytes from the subjects.

Metals in Hair. Ramakrishna et al. (Ref. 122) compared the concentrations of 17 trace elements in hair samples collected from 22 industrial welders, 15 locomotive shed workers, and 21 controls who worked or resided in Nagpur, India. Potassium was the most significantly elevated metal in hair shafts from welders, with a mean value 181% above that in hair from controls.

Investigations in Animals

In studies in which mild and stainless steel welding fumes were administered to rats by intratracheal instillation, Antonini et al. (Refs. 8 and 9) found that stainless steel welding fumes were cleared more slowly from the lungs, and induced a greater inflammatory response than did mild steel fumes.

Effects of Welding on Health, XI

Section One The Exposure

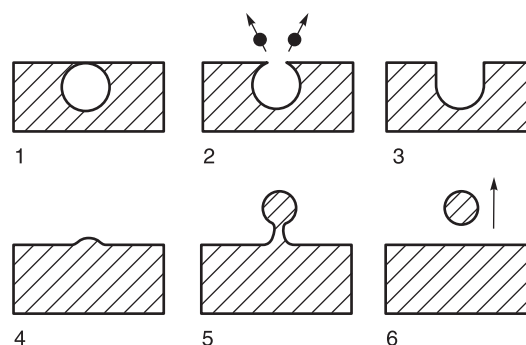
1. Fume Composition

Most of the material in the welding fume comes from the consumable electrode, which is partially volatilized in the welding process; a small fraction of the fume is derived from spattered particles and the molten welding pool. The electrode coatings, shielding gases, fluxes, base metal, and paint or surface coatings also contribute to the composition of the welding aerosol. Components of the source materials may be modified, either thermochemically in the welding zone or by photochemical processes driven by the ultraviolet light emitted during welding. Vaporized metal reacts with air, producing metal oxides which condense and form fumes consisting of particles which are primarily of respirable size. The composition and rate of generation of welding fumes are characteristic of the various welding processes, and are affected by the welding current, shielding gases, and idiosyncrasies of the welder. The concentration of the fume in the welder's vicinity is also a function of the volume of the space in which the welding is performed and the efficiency of fume removal by ventilation (Ref. 15).

Bunton (Ref. 26) performed experiments to explore mechanisms by which particles are spattered during the process of electron-beam welding. When welding aluminum, the greatest amount of sparking was produced by the most tightly focused beam. Sparking was enhanced by coating the metal surface with a film of oil or by punching holes in the surface along the weld. Welding of smooth stainless steel produced very little sparking, but many small sparks were produced during butt welding of a rough joint. A stainless steel plate which had produced no sparks when welded was heated in the presence of hydrogen; the hydrogenated plate sparked dramatically

when it was welded. Bunton also observed that sparks were more likely to occur at the start or finish of a weld or when welding over a previously-welded area. He concluded that these observations were consistent with a mechanism involving the development of sparks over pores in the metal (see Figure 1). These experiments were performed in support of a planned in-orbit test of the universal hand tool, an electron-beam welder developed in Ukraine for use on the space station, where hot particles spattered during welding would be a potentially lethal hazard because they could burn holes in the space suit.

Hewett (Ref. 63) measured the particle size distributions in fumes from SMAW and GMAW of mild and stainless steel collected in a laboratory hood. AWS fluoride flux 1/8-inch mild and stainless steel electrodes were used for SMAW. For GMAW, the mild steel welding wire



General Note: The bursting of a pore at the weld-pool surface may leave a cavity in the surface. The collapse of such a cavity could lead to emission of a drop as shown. Data from Bunton, Ref. 26.

Figure 1—Development of Sparks Over Surface Pores

was coated with copper and the stainless steel welding wire was uncoated. Samples for determination of bulk fume density and specific surface area analysis were collected on 37-mm filter cassettes. To calculate the particle size distributions in fumes from the different welding processes, samples were collected using a Multiple Orifice Uniform Deposit (cascade) Impactor (MOUDI) that had nine stages with cutpoints ranging from 0.071 μm to 15 μm .

The bulk fume densities and the specific surface areas of particles in fumes produced by GMAW were greater than those produced by SMAW. The differences were related to the welding process and not to the type of steel. Similarly, the mass distributions of particles were shifted towards the smaller particle sizes in fumes from GMAW compared with SMAW. Elemental analysis of the stages of the MOUDI showed that metals were evenly distributed throughout the range of particle sizes. Therefore, predictions of pulmonary deposition for the aerosol could also be applied to its constituent metals.

Hewett (Ref. 64) then used established models to estimate the inhalability, the respirability, and the deposition of GMAW and SMAW fume particles in different regions of the human respiratory tract. Based on the particle size distributions and bulk fume densities (Ref. 62), the models predicted that between 23% and 41% of the mass of the welding fumes characterized in the study would be deposited in the lungs, mainly in the alveoli. Total lung deposition was estimated to be 60% higher for GMAW fumes than for an equivalent mass of SMAW fumes, and the total surface area of the particles in the GMAW fumes was calculated to be nearly three times that of the SMAW fumes. Hewett hypothesized that the biological response to insoluble inhaled particles is proportional to their surface area, and suggested that welders exposed to GMAW fumes may be at greater risk than are welders exposed to SMAW fumes.

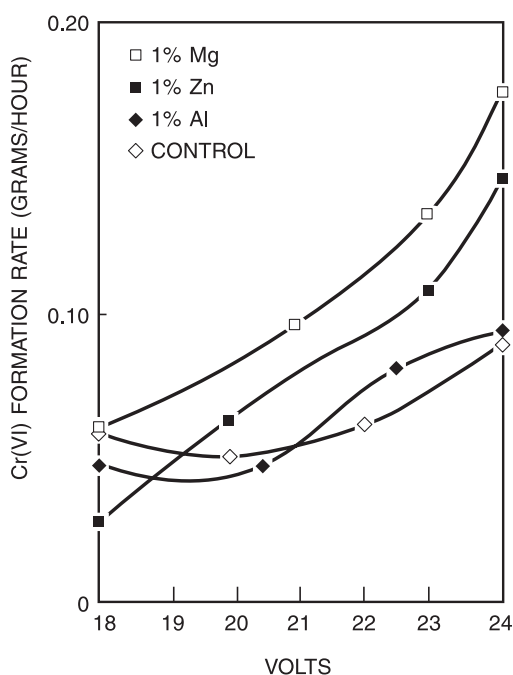
Perrault et al. (Ref. 114) examined physical and chemical characteristics of chromium-containing aerosols produced by SMAW of stainless steel and those produced by other industrial processes such as electrolytic plating and spray coating with chromate solutions. The oxidation state of chromium, and its distribution within the particles and among particles of different size ranges, were determined in each aerosol in order to develop air sampling schemes that would address hazards specifically associated with the different processes. Using energy dispersive X-ray analysis and transmission electron microscopy, they determined that 16% of the particles in the stainless steel welding fume contained chromium and that chromium levels were highest in particles with aerodynamic diameters less than 1 μm . Most of the particles were less than 0.1 μm in diameter, and, as has been reported by other investigators, the particles were aggregated into long chains. Analysis of the fumes collected

on the stages of an Andersen cascade impactor showed that the concentration of Cr(VI) was greater than that of Cr(III) in all particle size fractions. Different analytical methods yielded inconsistent data concerning the distribution of chromium among the particle size ranges. Electron spectroscopy for chemical analysis (ESCA) showed chromium distributed equally throughout the spectrum of particles, while secondary ion mass spectroscopy (SIMS) found chromium to be more highly concentrated in particles less than 1 μm in diameter.

Taking into account the morphology of the particles from SMAW of stainless steel, the greater proportion of Cr(VI) than Cr(III) in the aerosol, and the SIMS and ESCA analytical results, the authors concluded that a selective sampling regime is not required for these fumes. They recommended sampling for total dust and analyzing for soluble Cr(VI). (Welding stainless steel by GMAW and GTAW may produce different chromium compounds and, as a result, could require a different analytical scheme.) Different sampling schemes were recommended for the aerosols produced by the other processes (e.g., spray coating with chromate solutions and electrolytic plating) that were studied. Sampling of respirable dust was the recommended practice at the three other worksites of the study because chromium was not uniformly distributed among the different particle size fractions in the other aerosols examined.

Dennis et al. (Ref. 41) tested the effects of adding small quantities of reactive metals to the electrode core on the concentrations of ozone and Cr(IV) produced by GMAW. They used a metal cored electrode that had a mild steel sheath containing mostly iron with 1–2% manganese and a core containing iron powder and 10% chromium metal. The control electrode had no other additives, whereas the cores of three experimental electrodes each contained 1% of either zinc, magnesium, or aluminum. Welding of a mild steel base plate was conducted under controlled laboratory conditions using a shielding gas of 78% Ar, 20% CO₂, and 2% O₂.

The metal additives caused changes in both the fume formation rate (FFR: grams of fume generated per unit time) and the Cr(VI) concentration in the fume. The FFR increased for all electrodes as the voltage was increased from 17 to 25 volts (V). The FFR was lower than that of the control when 1% aluminum was added and higher than the control when 1% magnesium or zinc was added to the electrodes. At a welding voltage of 18 V, the Cr(VI) formation rate was lowest in fumes from electrodes containing zinc. However, since the zinc additive promoted a high FFR, especially as the voltage increased above 18 V, the total Cr(VI) produced by the zinc-containing electrode was higher than that produced by the control electrode at voltages greater than 20 V (see Figure 2). The Cr(VI) formation rate from the electrode



General Note: Data from Dennis et al., Ref. 41.

Figure 2—Cr(VI) Formation Rate at Different Voltages with Metal Cored Wires Containing Small Quantities of Manganese, Zinc, or Aluminum

containing aluminum was similar to that of the control and the rate was highest for magnesium-containing electrodes at all voltages. The authors concluded that addition of 1% zinc to the welding electrode can produce a significant reduction of Cr(VI) in fumes at a welding voltage of 18 V.

2. Ozone

Ozone can be produced by irradiation of molecular oxygen with ultraviolet (UV) light. It is a respiratory tract irritant, and chronic exposure to ozone can lead to the development of pulmonary diseases such as emphysema. An indirect health effect of ozone in welding emissions results from its ability to oxidize trivalent chromium [Cr(III)] in welding fumes converting it to the known carcinogen hexavalent chromium [Cr(VI)].

In an effort to reduce ozone concentrations in GMAW fumes, Dennis and Mortazavi (Ref. 40) used a modified welding gun that produces twin concentric shield gas

shrouds surrounding the arc in place of the standard single inert gas shroud. They found that ozone could be virtually eliminated by using an internal shield gas of argon with 5% CO₂ and 2% O₂ and an outer shield gas of either argon with 300 ppm nitric oxide (NO) or argon containing trace quantities (less than 1%) of ethylene.

3. Analytical Methods

3.1 Nickel. Butler et al. (Ref. 27) examined methods recommended in the United Kingdom for analysis of nickel in dusts collected from workplace air. Five different procedures for dissolution of different types of dust samples were evaluated, and all were found to meet the requirements for sample detection of the newly-established European and British exposure limits for nickel. Different procedures must be used for air samples obtained from different industrial processes, depending on the solubility of the nickel compounds. A hot plate digestion using only concentrated nitric acid was effective in solubilizing a range of pure nickel compounds commonly used in industry, but gave incomplete recoveries of refinery dusts and welding fumes.

3.2 Polychlorinated Biphenyls. In the 1950s and 1960s mixtures of polychlorinated biphenyls (PCBs) were often incorporated into paints and coatings used for metal surfaces, many of which remain on objects still in use. The PCBs could be released from these surface coatings during welding or maintenance. Welsh (Ref. 163) developed a method for extraction and analysis of PCBs in paint chip samples and applied it to six railroad car paint samples collected during a Canadian industrial hygiene survey. Three of the railroad car paint samples were shown to have PCB concentrations in excess of the Canadian environmental standard of 50 ppm. Another sample, from a vinyl coating on a hopper, contained 18,700 ppm of PCBs. Welsh concluded that there could be health risks to welders and other workers performing repairs on such materials.

4. Workplace Exposures

Vinzens et al. (Ref. 158) investigated the relationship between the concentrations of toxic components in samples of total dust and in samples of inhalable dust¹. The study was conducted in two wood workshops, in a lead battery factory, in an aluminum foundry, and in a repair

1. The inhalable particulate mass is defined as that fraction of an airborne dust that can be deposited anywhere in the respiratory tract. The particle size range is 0 to 100 μm (Ref. 3).

shop where aluminum was welded. Workers were equipped with two types of samplers, one for total dust and one for inhalable dust, and parallel breathing zone samples were collected. For the welding fumes, the median measurements of total and inhalable dust concentrations were nearly identical (4.0 and 3.8 mg/m³, respectively) probably due to the fine particle size of the welding aerosol. However, the proportion of aluminum in the welding fume was 1.4 times higher in the inhalable dust samples than in the total dust samples, indicating that determination of the aluminum content in the total fume might not adequately reflect the concentration of aluminum that could be inhaled. The other workplace dusts in the study were less homogeneous than welding fumes.

Hori et al. (Ref. 71) determined concentrations and size distributions of airborne welding fumes samples collected at 20 workplaces in 13 Japanese companies. Personal, area, and source samples were collected simultaneously. Stationary samples were collected in five general area stations, and personal samples were collected in the breathing zones of two welders in each workplace. The size distributions of the fumes were determined with cascade impactors at all sampling sites. The average fume concentration collected by personal samplers was 11.3 mg/m³, the average general area concentration was 0.4 mg/m³, and the average source concentration was 46.8 mg/m³. Mass median aerodynamic diameters of particles in the personal samples were 0.8 µm, and those of the area and source samples were 2.41 µm. The authors concluded that neither general area nor point source sampling is a reliable substitute for personal monitoring.

As part of a project on the "Health Risks of Welding" jointly sponsored by German and Norwegian government research agencies, Karlsen et al. (Ref. 79) collected fume samples from the breathing zones of four welders during 18 complete workshifts of SMAW of Inconel alloy. The Inconel alloy contained about 60% nickel and Inconel electrodes contained about 20% chromium. Total Cr, Cr(VI), Ni, Mn, and Fe concentrations are shown in Table 1. The authors compared the breathing zone concentrations of fume constituents from SMAW of Inconel with those from SMAW of a chromium and nickel alloyed steel determined in an earlier study (Ref. Karlsen 78). The median and mean nickel concentrations in the breathing zone during SMAW of Inconel were greater than those from SMAW of stainless steel while the median and mean concentrations of total Cr, Cr(VI), Fe, and Mn were marginally lower in the fumes from Inconel than had been found in the fumes from stainless steel welding.

Vasconcelos (Ref. 155) conducted an exhaustive study of the composition of fumes generated in a large, well-

Table 1
Concentrations of Welding Fumes and Components in the Breathing Zone During SMAW of Inconel Alloy

Fume Component	Mean Concentration (mg/m ³)	Range (mg/m ³)
Total fume	4.8	0.8–41
Nickel	0.260	0.033–2.9
Iron	0.340	0.120–1.5
Total chromium	0.120	0.0092–1.4
Hexavalent chromium	0.021	ND ⁽¹⁾ –0.180
Manganese	0.014	ND–0.092

General Note: Data from Karlsen et al., Ref. 79.

Note:

(1) ND indicates that there was one measurement below the detection limit.

ventilated factory room in Portugal, where SMAW of mild and stainless steel and, less frequently, automatic GMAW of mild steel were performed on variously-shaped metal pieces. Background area samples were taken at a central point in the workroom, at a height of 1.8 m and a distance of 9 m from the welding operation. Personal samples were collected in the welders' breathing zones for 2 to 4 hours. Fifteen elements were determined in each of the samples.

In the background area samples, the concentrations of each of the elements measured and of total dust were below the American Conference of Governmental Hygienists (ACGIH) Threshold Limit Values-Time Weighted Averages (TLV-TWA). A total of 124 breathing zone samples were taken during SMAW of mild steel; total fume concentrations ranged from 1.64 to 345 mg/m³ (see Table 2). For SMAW of stainless steel, there were 22 breathing zone samples, and the total fume concentration ranged from 2.6 to 50 mg/m³. Statistical analysis of data developed from these two sets of samples showed close correlations between the concentrations of the individual elements and that of the total fume.

For the 30 breathing zone samples taken during GMAW of mild steel, the total fume concentration ranged from 3.2 to 9.7 mg/m³, but there was little correlation between concentrations of the individual elements and that of the total fume. The authors concluded that the low background levels of fume indicated that the general ventilation in the welding room was good. The constant relationships between the concentrations of total fume and those of the fume components produced by SMAW of mild and stainless steel showed that total fume or

Table 2
Components of Welding Fumes from SMAW of Mild and Stainless Steel
and Automatic GMAW of Mild Steel Expressed as Percent of Total Fume

Fume Component	SMAW—MS ⁽¹⁾ 124 Samples	SMAW—SS ⁽²⁾ 22 Samples	GMAW—MS ⁽³⁾ 30 Samples
Iron	13	5	18
Potassium	12	9	4
Fluoride	8	3	2
Calcium	6	3	2
Manganese	3	2	1
Sodium	1	2	2
Zinc	0.4	3	NM ⁽³⁾
Aluminum	0.2	0.05	0.6
Magnesium (Mg)	0.2	0.1	NM
Lead (Pb)	0.1	0.04	0.05
Copper (Cu)	0.06	0.07	0.05
Chromium (Cr)	<0.04	2	0.05
Nickel (Ni)	<0.001	0.4	0.02
Beryllium (Be)	<0.003	0.0005	0.002
Cadmium (Cd)	<0.0001	0.0005	0.004

General Note: Data from Vasconcelos et al., Ref. 155.

Notes:

- (1) MS = Mild Steel.
- (2) SS = Stainless Steel.
- (3) NM = Not Measured.

other easily measured components of the fume such as iron or fluoride could be used by the industrial hygienist to estimate the concentrations of the harder-to-measure fume components such as chromium and nickel. They noted that GMAW produced generally lower levels of fumes, but because of the poor correlation between measurements of the relative concentrations of the fume components and of total fume, a simplified monitoring procedure could not be recommended for GMAW fumes.

In the second part of the study, Vasconcelos et al. (Ref. 156) used the same sampling data to examine the contributions of the shape of the work piece, the welder's posture, and local exhaust ventilation to the concentrations of contaminants in the breathing zone. Examination of the pieces welded when the 124 breathing zone samples were collected during SMAW of mild steel showed that fume concentrations, whether measured as total fume or as one of its components, were lowest in the samples collected during welding of open pieces, higher when welding pieces with cavities, and highest when welding closed pieces which had compartments that restricted removal of fume by local ventilation. Similarly, the concentration of fumes in the breathing zone increased when the welder's head was positioned over the work. The presence of local exhaust ventilation decreased breathing zone levels, but the efficiency of venti-

lation varied from piece to piece. In some cases, during welding of closed pieces, total fume was in excess of the TLV, with or without local exhaust, but the fume concentration was always lower when ventilation was used. The only fume component that was found to be higher than the TLV was manganese in fumes generated during welding of closed pieces, with or without local exhaust. Zinc levels increased by as much as fifteen-fold in the breathing zone when the objects being welded had been coated with a zinc-based paint.

The 22 samples of fumes from SMAW of stainless steel were collected mainly during welding of open pieces. Total fume, Cr(VI) (estimated as soluble Cr), total Cr, Fe, Mn, and fluoride were found in excess of the TLV in some of the fume samples. The 30 samples collected during GMAW operations were also collected during welding of open pieces, and the highest fume concentrations were found in samples taken while the worker was directly over the plume. Total fume concentrations higher than the TLV were observed in some samples, and there were possible excursions above the TLVs for iron and manganese. However, this welding area also contained pollutants from nearby shielded metal arc welding which probably led to overestimation of the fume concentrations produced during GMAW. The authors concluded that the shape of the work piece, the

welder's posture, and local exhaust markedly influenced the pollutant levels in the welder's breathing zone. Some of the local exhaust ventilation employed in this welding room was insufficient for the task, due either to improper positioning or inadequacy of the ventilator. The major health hazard observed by the authors was Cr(VI) from SMAW of stainless steel.

Bellido-Milla et al. (Ref. 18) analyzed welding fumes samples collected over a 3-month period in six work areas of a naval shipyard in Cadiz, Spain. Environmental samples taken in the general work areas were all below the TLV values for total fume and for all of the fume components measured (Fe, Mn, Cu, and total Cr). Breathing zone fume concentrations were highest in the dock and basin areas of the shipyard where they were in excess of the ACGIH TLV in 72% and 82% of the samples, respectively. Breathing zone levels of iron and manganese were in excess of the TLV in most of the work places in the shipyard. The highest average levels of total fume (21 mg/m^3) were found in breathing zone samples collected when horizontal pieces were welded, and the lowest total fume levels (4 mg/m^3) were in samples taken when the piece being welded was overhead. Similarly, welding in enclosed, unventilated spaces resulted in greater average breathing zone concentrations of iron (2 mg/m^3) than were found in samples taken during welding in open, ventilated areas (0.4 mg/m^3). The shape and size of particles determined by light and electron microscopic analyses indicated that a large fraction of the mass of particles could reach the gas exchange region of the lung.

Liu et al. (Ref. 92) measured breathing zone lead concentrations and particle size distributions in aerosols produced during lead battery manufacturing. In one of the battery assembly operations, a high voltage (HV) welding machine is used to join cells within the battery after it is assembled. After the battery cover is sealed onto the case, the lead posts are formed and attached using a welding torch and a mold. Aerosol samples were collected in the workers' breathing zones using a cascade impactor connected to a personal sampling pump. Samples from each impactor stage were digested in acid and analyzed for lead by atomic absorption spectrophotometry (AAS).

For HV welding, the mean concentration of lead was $26 \text{ } \mu\text{g/m}^3$ but particles greater than $10 \text{ } \mu\text{m}$ in diameter accounted for 71% of the mass of the samples. The authors estimated, on the basis of the particle size distribution, that 34% of this lead aerosol could enter the thoracic region and 16% could enter the deep lung where it would be available for transport into the bloodstream. The sources of the lead aerosol produced during the HV welding process were lead fume from the welding process and particles that came loose from the pasted grid. Lead particulate derived from mechanical processes

would have a larger mass median aerodynamic diameter (MMAD) than that derived from processes involving vaporization and condensation. Lead concentrations were higher in the other battery manufacturing operations, which did not involve welding, ranging up to $90 \text{ } \mu\text{g/m}^3$ in the area where the grids used to make up the battery cells were cast. In all of the operations in the battery plant, the mass fraction of the aerosol greater than $10 \text{ } \mu\text{m}$ in diameter exceeded 70%.

Linnainmaa et al. (Ref. 91) used electron microscopy and elemental X-ray microanalysis to characterize particles produced during welding, brazing, and grinding of stellite (an alloy containing primarily cobalt, chromium, and tungsten) or hard metal (an alloy containing tungsten carbide and 6 to 7% cobalt) in Finnish tool manufacturing companies and blade repair shops. The particles produced during welding of stellite contained mainly cobalt and iron, while the principal components of particles produced by grinding the stellite tips were chromium and cobalt. Particles collected during brazing and grinding of hard metal contained cobalt, tungsten and iron. The mean of all the cobalt concentrations measured in the breathing zone and at stationary sampling sites was below the TLV of $20 \text{ } \mu\text{g/m}^3$. The mean cobalt concentration was $7 \text{ } \mu\text{g/m}^3$ in personal samples collected from the brazers. The mean breathing zone concentration of cobalt was $40 \text{ } \mu\text{g/m}^3$ for workers at manually operated grinding machines. These results differed from those of Teschke et al. (Ref. 144) who found that chromium, but not cobalt, was a constituent of fume generated by welding stellite tips onto saw blades (See Section 8.1). The reason for this discrepancy is unknown, but Linnainmaa indicated that cross contamination of samples with cobalt-rich aerosols from wet grinding operations was possible. The work of Linnainmaa et al. (Ref. 91) is in accord with that of Ferri (Ref. 47) who identified cobalt in fumes from gas metal arc welding of stellite. Concentrations of cobalt in fumes from oxyacetylene braze welding were lower than those in fumes from GMAW, which Ferri attributed to the high evaporation point of cobalt and the higher temperatures associated with GMAW. Neither Linnainmaa nor Teschke described the welding methods used during their investigations, so that whether this could factor into the discrepancies between the two studies is unknown.

Begin et al. (Ref. 17) described a computerized data bank using occupational exposure data collected since 1976 in Montreal, Canada. The data bank contains over 20,000 data points, including 457 measurements of the airborne concentrations of welding fumes (total particulate and/or fume components). An exposure profile for arc welders employed in SMAW, developed from a composite of the data collected during welding, contains measurements of 15 contaminants. All available measurements were used, whether from area samples or from

personal monitors. Most of the data were obtained during sampling periods of less than 3 hours. The data are linked to specific companies and processes so that a government industrial hygienist can identify potential sources of excessive exposure.

5. Electromagnetic Radiation

Tenkate (Ref. 143) reviewed the types and levels of electromagnetic radiation associated with welding, their measurement, health effects, and protective devices and engineering controls used to limit welders' exposure. Factors that influence the spectrum and intensity of the radiation produced during welding include the welding process employed, the type, composition, and state of wear of the electrode, the base metal, the shielding gas, arc current and voltage, the geometry of the weld, and ventilation. The ignition phase for GMAW lasts about 25 milliseconds, during which time the spectral emission rapidly increases in intensity and then falls off to a stable level. In the ultraviolet (#UV) region, the peak radiation intensity during ignition is about ten times the level at steady state. For most arcs during steady state, UV irradiance is proportional to the square of the arc current. Decreased arc gap also results in decreased irradiance, particularly with GTAW. Smoke and fumes scatter and absorb UV radiation. Ultraviolet radiation is increased when argon rather than carbon dioxide is used as the shielding gas or when the base metal is highly reflective. Tenkate stated that the greatest hazards from UV radiation occur during argon-shielded GMAW of ferrous alloys or aluminum and during helium-shielded GTAW

of ferrous alloys. Infrared radiation from welding presents a minimal hazard compared with that from UV and visible light. Blue light radiance, at the low end of the visible spectrum, between 420 and 430 nanometers (nm), is the most hazardous to the eye. Control of radiation exposures can be achieved by use of personal protective equipment and by engineering controls. The latter can include increasing the distance of other welders and non-welders from the welding site, use of nonreflective materials and paints in welding areas, and enclosing individual work areas with permanent or temporary screens. Semitransparent curtains and screens are increasingly used for this purpose.

Knuschke and Barth (Ref. 83) used polysulfone film dosimeters to measure the daily dose of UV radiation received by workers exposed to arc welding in a European railway repair station who had complained of eye problems. The polysulfone film, which undergoes changes in optical transmission upon exposure to UV light, had been calibrated by exposure to measured levels of monochromatic radiation (295 nm). The dosimeters were worn for five days on headbands inside the protective helmets by five welders and at chest level by seven nonwelding assistants. The welders' daily exposures ranged from 230 to 2110 J/m², which is 7.5 to 70 times the German occupational limit for UV exposure of 30 J/m² per 8-hour day. The seven nonwelding assistants were exposed to a range of 120 to 360 J/m² (4 to 12 times the limit).

Klebanov (Ref. 82) measured the UV light output of various welding techniques in a factory in the Republic of Belarus. The findings are summarized in Table 3. The applicable industrial standard was 1.0 watt per square meter (W/m²) for both UVB (wavelengths of 280–315 nm)

Table 3
Ultraviolet Radiation in the Work Area Produced by Welding and Cutting Techniques

Welding/Cutting Technique	Strength of UV Irradiation in the Working Zone (W/m ²)					
	UVA		UVB		UVC	
	Mean	Range	Mean	Range	Mean	Range
SMAW	15.2	5–45	5.9	4–14	13.7	6–18
Automatic Welding (CO ₂)	16.1	4–26	7.5	6–17	8.6	4–15
GMAW (Argon)	9.4	6–14	5.5	5–7	33.5	20–44
Oxypropane cutting	0.001	0–0.1	0.002	0–0.05	0.02	0–0.05
Oxyacetylene Welding	0.06	0–0.13	0.02	0–0.06	0.004	0–0.02
Air Plasma Cutting	2.3	—	1.2	—	1.1	—
Plasma Deposition	—	11–15	—	11–15	—	11–15

General Note: Data from Klebanov, Ref. 82.

and UVC (100–280 nm); there was no standard for UVA (315–400 nm). The highest levels of all forms of UV radiation were produced by electric arc welding techniques and by plasma deposition. The radiation intensity depended upon the welding current, the electrodes used, the amount of local ventilation, and the distance from the source. For air plasma cutting, the levels of UVB and UVC were close to the industrial standard. Radiation from oxyfuel gas welding was several orders of magnitude lower than that from arc welding, due to the greatly lower temperatures involved. Because UV radiation levels measured in the work area during electric arc welding and plasma deposition were consistently higher than the industrial standard, Klebanov recommended that UV levels be routinely monitored in the workplace and that new regulations for their control be adopted in Belarus.

When a spot welder in a Canadian automotive assembly plant complained of red, irritated eyes, he was advised by his eye care practitioner to wear a dark (shade 3) eyeshade. Other welders also began to adopt this protective measure, and plant safety officials became concerned that the reduced visibility might be a safety hazard. Chou and Cullen (Ref. 33) evaluated the ultraviolet (UV) light exposure at the work site and analyzed the visual demands. Each weld was accomplished with a 50 microsecond current discharge; exposure time was less than 10 seconds per weld. Many welds produced no visible radiation but, when thicker metal sections were welded, bright flashes of visible light were produced which were accompanied by showers of molten metal particles propelled at high speed up to 3 meters from the workstation. Optical radiation was measured at a manual spot welding station using two instruments located 1 meter from the weld site. In the worst case, the maximum total UV irradiance measured was 0.88 microwatts per square centimeter ($\mu\text{W}/\text{cm}^2$). In general, the UV irradiance levels measured during spot welding with electrodes operating at 10 to 15 kA and 10 to 20 V were several orders of magnitude below recommended industrial safety limits. Based on an estimated threshold level of 0.004 joules/ cm^2 (1 Watt = 1 joule/second) for UV-induced photokeratitis, the authors calculated that, at the worst case irradiance level of 0.88 $\mu\text{W}/\text{cm}^2$, a total of 76 minutes of continuous welding would be required to produce this injury, which, due to the intermittent nature of the spot welding, is far in excess of the total possible in a working day. The authors concluded that the eye irritation was more likely to have been caused by the shower of sparks produced by welding thick materials and that safety glasses with clear polycarbonate lenses would provide appropriate eye protection. They calculated the reduction in effective illuminance that would be caused by shade 3 filters and concluded that their use would create a hazardous situation in the workplace.

6. Electromagnetic Fields

6.1 Exposure to Electromagnetic Fields. Floderus et al. (Ref. 51) assessed workplace exposures to extremely low frequency electromagnetic fields (EMFs) in an attempt to determine the distribution of such exposures among male workers in Sweden and to estimate average exposures in different occupational groups. The 1,098 men in the study had been selected at random in 1980 from the working-age population of eleven counties. Analyses of exposures were restricted to the 100 most common Swedish occupations in 1990. Exposure to extremely low frequency EMFs was measured at the job site each of the subjects had held for the longest period of time between 1973 and 1987. Workplace exposures were assessed by dosimetry between 1989 and 1991. Because many of the subjects had retired or changed occupations, it was often necessary to fit a person other than the target subject with the dosimeter. In some cases, surrogate workplaces had to be found as well. The dosimeters measured EMFs in the range of 40–400 hertz (Hz), and their maximum reading was 2500 microtesla (μT). They were worn on a belt at the waist for at least 6 hours of the workday. EMF readings were recorded every second, and these records were downloaded to a computer. Individual EMF exposure results were recorded for 809 of the 1,098 subjects. Of the major occupations studied, welders had the highest exposure to EMFs. The mean workday exposure for welders was 1.90 μT , and the maximum was 142 μT . For comparison, the occupational group of secretaries, typists and clerks had an average exposure of 0.12 μT and a maximum of 2.5 μT . Among uncommon occupations not included in the top 100, train engine drivers and “glass-makers and blowers, [and] kiln operators” had mean EMF exposures greater than those found for welders.

6.2 Interaction with Cardiac Defibrillators. The operation of an implanted cardioverter defibrillator is dependent on the detection of electrical activity of the heart. There has been some concern that EMFs generated by external sources in the work place could interfere with the defibrillator causing temporary suspension of the detection of abnormal cardiac activity. Fetter et al. (Ref. 48) measured the strength of magnetic fields generated by welding equipment in a study of their effects on the proper functioning of cardioverter-defibrillators. The magnetic flux density of a Lincoln AC2255 arc welder operated at 225 amperes (A) was 40 gauss (40 G or 4000 μT) at the cable surface and 1.2 G (120 μT) at 2 feet from the cable. For a Lincoln DC Weld Pak at 88 A, the corresponding measurements were 44 and 0.5 G (4400 and 50 μT). Eleven male patients with implanted cardioverter-defibrillators were instructed to weld with the defibrillator positioned one foot or less from the welding arc. The defibrillators were temporarily reprogrammed to en-

hance the probability of inappropriate operation of the device due to electromagnetic interference, their operation was monitored, and the data were stored in a computer. Since none of the welding equipment produced measurable interference with any of the implantable defibrillators, the authors concluded that it was safe for them to return to work as welders if they undertook common-sense safety precautions, including periodic individual evaluation of the interaction of EMFs generated in the workplace with the device in the patient. This conclusion was echoed by Embil and Geddes (Ref. 45), citing their own experience with a patient who had successfully returned to the workplace as an arc welder for a period of 4 years after receiving an implanted defibrillator (Ref. 46).

Pinski and Trohman (Ref. 116) maintained that interaction of EMFs with implanted cardioverter-defibrillators has not been well studied, and, while "negative bias toward these patients should be avoided," an individualized approach such as that described by Embil et al. (Ref. 47) was recommended, with consideration given to job retraining of younger patients or early retirement for older patients. These authors also cautioned that cardioverter-defibrillators that can be deactivated by EMFs should not be implanted in patients who are likely to encounter strong EMFs.

7. Hygiene and Work Practices

7.1 Protective Gear and Equipment. Liu et al. (Ref. 93) measured metal fume concentrations inside and outside the welding helmet in the personal breathing zone of 20 welders (15 men and 5 women) recruited via advertisements and from members of the metal trades unions in the San Francisco, California area. Exposures were carried out in an environmental exposure chamber while the welders performed electric arc welding on galvanized mild steel using a cellulose-covered electrode. For measurements inside the welding helmet, air samples were collected from a point near the welder's mouth. The outside samples were collected at the shoulder near the lower edge of the helmet in the lapel area. The concentrations of iron and zinc inside the helmet did not differ substantially from those outside the helmet. The mean ratio of inside-to-outside iron concentrations was 0.9; the median ratio was 0.96. The authors concluded that the use of the welding helmet provides unreliable and ineffective attenuation of exposure to welding fumes.

Excessive carbon dioxide from re-breathing expired air is a source of discomfort and may cause metabolic and ventilatory reactions such as headache, shortness of breath on mild exertion, and slight acidosis. Stromberg (Ref. 141) developed a method, using a respiratory pl-

ethysmograph and a mass spectrometer, for measuring the volume of CO₂ in the dead space of a welding visor and the fraction of CO₂ in the inspired air of welders wearing visors. Both measurements were higher during mouth breathing than during nasal breathing and were also higher after exertion. The mean inspired CO₂ concentrations for subjects wearing the visor were higher in all cases than the TLV of 5000 ppm.

The effect of normal wear on the frictional properties of shoe heels and soles was tested by Gronquist (Ref. 59). Slip-resistance was measured in safety shoes that had been worn for 2 to over 8 months by 27 welders, plumbers, and sheet-metal workers in a Finnish ship-building company. Three different shoe models, with heels and soles made of polyurethane (PU), nitrile rubber (NR), or styrene rubber (SR), were collected and tested on a stainless steel floor and on a rough plastic anti-slip carpet that had been made slippery with either glycerol or a detergent-water solution. Shoes with polyurethane heels and soles were the most slip-resistant in all of the tests, and their slip-resistance improved by 66% when the shoes had been worn for some time. The slip-resistance of NR soles and heels increased by 27% after use, whereas that of SR soles and heels decreased by 7%. The author suggested that worker safety could be increased by slightly abrading the heels and soles to break in the safety shoes before they are issued to the wearer. The author also noted that the use of heels with a beveled or rounded back edge reduces the contact pressure between the shoe and the floor in the crucial fraction of a second after heel strike, helping to establish friction in order to avoid a slip.

7.2 Traumatic Injuries. Zwerling et al. (Ref. 171) conducted a survey of traumatic injuries seen in nine hospitals in rural Iowa and found that construction workers visited the emergency rooms 2.7 times more frequently than did workers in nonconstruction occupations, and that work-related injuries were 4.7 times more frequent among the construction workers. All male and female workers with known occupations who were treated for traumatic injuries during the 1-year period September 1993 to August 1994 were included in the survey. Only 3% of the working population of the counties served by the nine hospitals worked in construction and, similarly, construction workers represented only a small fraction of the workers treated at the hospitals surveyed. Only six female construction workers were identified among the injured. The proportion of traumatic injuries that were work-related was higher among the construction workers than among the nonconstruction workers: 48% of the injuries were work-related among male construction workers, compared with rates of 39% and 24% among all employed males and all employed females, respectively. Of the work-related injuries, the proportion of burns was

higher among the construction workers, but, with the exception of falls from ladders, the proportions of work-related injuries attributable to other causes, such as being struck, crushed, or pierced by objects, were similar in both groups. Contact with hot tar among roofers and “flash burns” to the eyes of welders were the leading causes of work-related burns to construction workers in the study population.

7.3 Electrocution. Approximately 5% of work-related fatalities have been attributed to electrical injury. Risk factors include use of electric power tools with wet or perspiration covered hands which decreases resistance to electricity, use of improperly grounded portable arc welding equipment, and working with power tools in wet environments. Most electrical injuries occur during the summer to males, 20 to 29 years of age. This phenomenon is related to the use of outdoor equipment and to excessive perspiration. High and low voltages are about equally responsible for fatalities. Even very low voltage can cause death, and some authorities consider that anything higher than 25 volts is potentially lethal (Ref. 111). Ventricular fibrillation is a common cause of death from electric shocks. The duration of the exposure is important in determining whether or not an effect will occur, particularly at low voltages. Of major importance is the point of contact. Dry skin is far more resistant to electrical currents than is wet skin and thick skin, such as a calloused palm, is more resistant than more tender skin on other areas of the body.

These points, from a review article by Pasternak (Ref. 111), were well illustrated in an independent report by Peng and Shikui (Ref. 113) which described seven cases of death from electrocution by low voltages (less than 80 V) from AC and DC electric welding machines (see Table 4). All fatalities were male welders, average age 27 years. All of the incidents occurred during the summer in

closed environments with high temperature and high humidity. Examination at autopsy indicated that the contact sites were the thinner skin of the chest, neck, face or arm. The burns were severe, indicating that the electrocution time was not short. Perspiration on the contact sites further reduced local resistance, allowing the low voltage to result in an appreciable current in the body. The contact sites were near or on the chest, so that the electric current could easily have affected the heart, lungs or respiratory muscles. All of the welders had been in good health at the time of their accidents. Peng and Shikui surmised that some of them might have suffered heat stroke before the incident. Alternatively, the hot and humid environment may have made the victims more subject to fatigue and slower to react.

7.4 Hazards Faced by Tradeswomen. In 1990, women constituted only about 2% of the construction workforce in the U.S., but this percent is expected to increase substantially during the next decade (Ref. 57). The subgroup of female welders may be expected to parallel this trend. While the literature concerned with hazards to male welders is becoming substantial, little is known about hazards that may be peculiar to female welders, largely because their numbers have been too few to allow for collection of meaningful data.

Goldenhar and Sweeney (Ref. 58) interviewed 51 female construction workers, some of whom were welders, and determined what the women viewed as their greatest workplace hazards. Some of these hazards involved sociological factors related to gender differences. One of the most important of these was related to differences in childhood experiences: boys tend to become familiar with tools, mechanical processes, and their related hazards whereas women may not be exposed to such hazards until they receive on-the-job training. Thus, standard training sessions, traditionally designed for male work-

Table 4
Details of Welding Electrical Fatalities

Age	No Load Voltage (V)	Welding Voltage (V)	Electric Burn Site	Comments
26	75 (DC)	45	Inner side of arm	Temperature and humidity high at worksite; victim was sweating.
20	75 (DC)	45	Neck	High temperature, poor ventilation; victim was sweating.
28	65 (DC)	36	Chest and armpit	Shoes and socks wet with sweat.
41	60	—	Anterior arm	Temperature very high at worksite.
29	60	—	Above eyebrow	Worksite humid and hot.
22	47	24–30	Chin and abdomen	
22	75	45	Chin and lower lip	High temperature and humidity.

General Note: Data from Peng and Shikui, Ref. 113.

ers, may be insufficient to properly prepare women for the hazards they are about to encounter in the workplace. Perhaps even more important is the lack of protective workplace gloves and clothing designed for women. Several women complained that they were outfitted with gloves that were much too large. Ill-fitting gloves make it difficult to properly grasp objects. Oversized gloves and other loose-fitting clothing can get caught in moving parts of machinery. Other concerns included: exposure to chemical and physical agents; injuries from lifting, bending, twisting, and falling; and health and safety risks related specifically to tradeswomen (e.g., unsatisfactory restroom facilities and psychosocial stressors). The authors concluded that engineering, behavioral, and administrative interventions can successfully address many of these concerns.

Quinn et al. (Ref. 119) addressed some of the same issues. In addition, they noted that tools designed for use by the average man may be unwieldy for most women and may increase the exertion required for a given task which can cause ergonomic problems. They also noted that women who may be placed in the position of being an unwelcome minority in the workplace may feel pressured to attempt work that is unsafe.

7.5 Safety. Jarvinen et al. (Ref. 76) described a design procedure which used three-dimensional computer simulation models of the work environment, to optimize safety and ergonomic considerations in automated manufacturing systems. In a case study, this procedure was used to develop safety procedures for a welding robot system for GMAW of long beams in one station and automobile body parts in two others. In the safety-oriented design, a worker must pick up an enabling device before being able to enter the area of the robot welder, and must keep buttons pressed to keep the robot operating. The maximum arm speed of the robot is automatically reduced to 250 mm per second while the worker is in the welding area. The authors concluded that the use of a virtual reality tool allows the designer to perceive the work from an operator's point of view in the development of safe working environments.

7.6 Hazard Surveys. Tharr (Ref. 145) summarized the hazards to workers found by the Occupational Safety and Health Administration (OSHA) during health and safety consultation visits to small industrial sites in Colorado. At all 132 sites visited for safety inspections in 1990, welding and brazing accounted for an average of 10.4 identified hazards per 100 workers. Other types of hazards were much more prevalent. There were 113 electrical hazards per 100 employees. Other notable hazards were associated with machinery, means of egress, walking or working surfaces, and flammable or combustible liquids.

Hale et al. (Ref. 60) described the National Occupational Health Survey of Mining, which has been conducted in 491 selected U.S. mines by the National Institute for Occupational Safety and Health (NIOSH). Worksite data have been collected in seven exposure categories: generic chemicals, trade name products, physical agents, musculoskeletal overload conditions, welding processes, grinding metals, and bulk settled dust. A computerized query system has been developed which allows access to the data in order to assess hazards to mine workers, including welders employed in the mining industry.

Section Two

Effects of Welding on Human Health

8. Respiratory Tract

8.1 Pulmonary Function. Over the years, numerous studies have addressed the effects of welding fumes on the respiratory tract as measured by lung function tests that determine the capacity of the lung and its ability to move air. Many of these tests are performed using a simple instrument called a spirometer which measures the flow rate and volume of expired air. Table 5 provides the definitions and abbreviations for some common lung function tests, including those used in the studies discussed below. The reactivity or responsiveness of the airways can be measured by administering allergens that may be encountered in the workplace or by challenging with nonspecific substances such as methacholine or histamine and measuring the dose necessary to induce a standard decrease in volumetric flow rate as measured by forced expiratory volume in 1 second (FEV₁). Positive responses at relatively low doses of the provocative agent are indicative of asthma. Because the lung capacity of healthy individuals greatly exceeds the demands of ordinary occupations, a significant loss of function can occur, and may be detected in lung function tests, before respiratory symptoms develop. Declines in lung capacity and air flow normally occur in males after age 25 (Ref. 21). Large groups of healthy subjects have been examined in order to establish the normal range of lung function and to develop adjustments for age, height, sex, and race.

Beckett et al. (Ref. 16) compared changes in lung function, airways responsiveness and respiratory symptoms in 51 shipyard welders and 54 controls observed in four annual examinations. They also examined changes in lung function that occurred across a workshift and compared them with changes that occurred during a nonworking day

Table 5
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. ⁽¹⁾
Residual Volume	RV	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.
Diffusing Lung Capacity for Carbon Monoxide	DLCO	A decrease in the pulmonary diffusing capacity, as measured by DLCO, may be seen in patients with diffuse interstitial disease who have normal spirometric tests.
Airway Responsiveness to Methacholine	PD ₂₀	The provocative cumulative dose of methacholine causing a 20% decrease in FEV ₁ .
Forced Expiratory Flow Mid Range (25–75%)	FEF _{25–75}	Flow rate measured during forced exhalation.
Terminal Flow (75–85%)	FEF _{75–85}	Reductions in FEF _{75–85} indicate impairment in small airways (alveolar region of the lung).
Maximum Expiratory Flow	MEF ₂₅ MEF ₅₀ MEF ₇₅	Measured at 25% of FVC. Measured at 50% of FVC, also known as maximum mid expiratory flow (MMEF). Measured at 75% 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.
Mean Transit Time	MTT	Derived from mathematical analysis of flow-volume curves.

Note:

(1) 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.

in a group of 49 welders, 32 of whom also participated in the 3-year study.

In the workshift study, spirometric lung function tests (FEV₁, MEF₅₀, and FVC) were administered at the beginning and end of a work day and also at the beginning and end of a day off from work. The average duration of active welding was 4 hours during the 8-hour workshift, and only 33% of the welders reported having used a respirator during that time. The aggregate number of respiratory symptoms (cough, chest tightness, phlegm) reported by the welders was low, but the total number of symptoms increased during the welding day and decreased during the nonwelding day for both smoking and nonsmoking welders. A small, but statistically significant, decline in

MEF₅₀ was seen on the welding day as compared with the day when welding was not performed.

The subjects had welded stainless steel for an average of 9 years at the start of the 3-year study. Controls were draftsmen and technicians employed in the same shipyard, living in the same community, and without any current or previous welding exposure. Negative pressure respirators were provided to all of the welders in the shipyard, but their use was at the discretion of the welder. Local exhaust ventilation was routinely used during welding in enclosed spaces. Each of the welders and controls was subjected to spirometric tests and to high-dose methacholine challenge (measured by the PD₂₀) at yearly intervals. These tests were usually done at the end of a

workshift. Each worker provided annual work histories which were used to calculate an index of annual exposure (the percentage of a full-time working year spent in active welding during the year prior to each respiratory evaluation). This factor declined after the first year due to work stoppage, reduction in demand for welding, and migration out of welding by some of the subjects. None of the welders who left the trade reported doing so because of a respiratory condition (although three left because of work-related back injuries). During the first year of the study, 35% of the welders reported that they experienced cough, phlegm, wheezing, and chest tightness during the work week, with improvement on weekends or holidays. These symptoms were significantly more frequent among welders than among controls throughout the study, but they diminished as welding exposure diminished during the course of the 3-year study. The frequency of symptoms of chronic bronchitis, persistent wheeze, and dyspnea (difficulty breathing) on exertion did not differ between welders and control subjects. The mean annual decline in FEV₁ among welders older than 25 was 4 mL per year, which is consistent with the annual rate of decline in the general population. There was no excess decline in lung function in welders compared with controls, nor was there a significant effect of welding on airway reactivity to methacholine in welders compared with controls. The authors concluded that welding is associated with a transient, across-workshift decrement in maximal mid-expiratory flow (MEF₅₀) and also with reversible, work-related respiratory symptoms. However, no decline in lung function or increase in airways reactivity was seen among the welders over the 3-year observation period, which, as stated by the authors, was not optimal for detecting a chronic effect on lung function.

In 1990, Chinn et al. (Ref. 31) reported that lung function in welders and caulker/burners was diminished compared with that of other tradesmen in a British shipyard. Most of the subjects of that study had worked in the shipyards before the introduction of exhaust ventilation in the early 1970s. In 1980, Chinn et al. (Ref. 32) initiated a prospective study of lung function in a cohort of younger welders and caulker/burners whose welding experience would have begun after the introduction of exhaust ventilation. A total of 222 welders and 194 caulker/burners from four shipyards on the river Tyne participated in the study. The welders were divided, according to self-reported information, into those who consistently used local exhaust ventilation and those who did not. The control group consisted of electricians and other tradesmen from the same shipyards. All study participants were born after 1953.

Participants responded to a respiratory symptom questionnaire and underwent anthropometric and lung func-

tion testing at the start of the study and again after 6 or 7 years. Initial assessments were conducted between 1980 and 1984. Welders and caulker/burners were grouped together for most analyses because their scores for respiratory symptoms and lung function were found to be similar throughout the study.

In the interval between the initial and final assessments of lung function, 478 of the men had left the shipyard, mainly due to lay-offs. Of the remaining 146 men, 139 were reassessed, as were 207 of those who had left. Significantly more of those who were unavailable for the final health assessments had initially reported having respiratory symptoms than had those who were available for follow-up assessments. Of the welders and caulker/burners who had left the shipyard and were given follow-up examinations, eleven were doing comparable work in other shipyards, 46 were following their trade in other industries, and 83 had no recent fume exposure. No differences in lung function were found between the non-welding tradesmen who had remained at the shipyard and the entire group who had left the shipyard. Lung function was significantly diminished in the group of welders and caulker/burners who were still active at the shipyard compared with all other workers who were reassessed (including the former welders and caulker/burners). This decline in lung function was shown by significant decrements in forced expiratory volume (FEV₁), peak expiratory flow rate (PEFR), and mean transit time (MTT) and a significant increase in residual volume (RV).

The effects of atopy (positive response to skin tests with common allergens) were confined to smokers and were not included in the final analysis. The effects of smoking and of exposure as a welder or caulker/burner on the annual decline in FEV₁ were very nearly equal and were additive. In this cohort of young welders and caulker/burners, there was a smaller decline in FEV₁ among those who reported using local exhaust than among those who did not, but this beneficial effect was not statistically significant.

In the subgroup of younger shipyard welders who admitted to not using their ventilation equipment at all times, there was a deterioration in FEV₁ which did not improve among those who had left the shipyard (an average of 4 years) before the reassessment. Welders who had used exhaust ventilation still experienced some decline in respiratory function, as measured by PEFR, but this was reversible. The authors noted that FEV₁ and PEFR were the most useful lung function measurements for assessing the respiratory health of welders and caulker/burners. Other indices were at most just confirmatory, and in the case of lung volume measurements, such as FVC, they were mainly uninformative. Although the industrial hygiene practices during the period of

study did not prevent development of mild respiratory impairment, the authors noted that these effects were reduced and appeared to be reversible in those who had taken advantage of local exhaust systems.

Some of the welders who participated in the local exhaust ventilation study were combined with welders from a second shipyard to form a larger cohort of 1,005 shipyard workers used by Chinn et al. (Ref. Chien 30) to study the relationship between lung function and body mass. Lung function tests (FEV_1 and FVC), physical examinations including measurements of body mass and body fat, and questionnaires concerning exposures and respiratory symptoms were administered at the start of the study and at the final reassessment, approximately 7 years later. During those 7 years, body mass increased for the youngest subjects and decreased for the oldest. Increases in the body mass index (weight divided by height squared) were significantly correlated with decrements in FEV_1 and FVC. Neglecting the effects of body mass changes could, according to the authors, lead to erroneous conclusions in studies of changes in lung function over time.

The usefulness of spirometry in screening for early detection of declines in pulmonary function that may be associated with exposure to welding fumes was examined by Rossignol et al. (Ref. 126). Spirometric tests and questionnaires concerned with respiratory symptoms were administered twice over a 5-year interval to 229 welders and cutters. The subjects were from 31 metal manufacturing plants in Montreal, Canada, and had a mean age of 40 years. Lifetime exposure was calculated from the job history of each welder and an industrial hygienist's estimation of fume concentrations encountered in each type of job. The welders had typically worked in open spaces without ventilation systems. The average fume concentration during active welding was estimated to be 5 to 6 mg/m³. Exposure to welding fumes was not found to be significantly associated with any of the spirometric test results except in the group of welders older than 45, for whom the FEV_1/FVC ratio indicated that workers with longer cumulative exposures to welding fumes had better lung function than did those with less cumulative exposure. The authors noted that their results were not in accord with those of Chinn et al. (Refs. 31 and 32). Factors that could have contributed to the differences in results include the inherent errors in the spirometric tests, possible misclassification in the exposure histories, and the short duration of the follow-up period, which they stated was "borderline" for a longitudinal study. They concluded that screening for decline in pulmonary function could be accomplished through the periodic administration of questionnaires, and that spirometry should be reserved for diagnostic purposes.

Sobaszek et al. (Ref. 135) compared pulmonary function changes in 130 stainless steel welders, 109 mild steel welders, and 234 controls recruited from eight French factories engaged mainly in shipbuilding or tank manufacture. Controls were matched to welders according to age, socioeconomic stratum, and tobacco use. Work history (including time spent welding, respiratory protection employed, and exposure to asbestos and silica) and respiratory symptoms were determined by questionnaire. After adjustment for tobacco use, no significant differences in lung function were found between the two groups of welders or between the welders and the controls. Among stainless steel welders, the number of years of welding experience was associated with a small deficit in mid-range expiratory flow rates (FEF_{25-75}). Stainless steel welders had significantly greater incidences of dyspnea on exertion, sputum production, and cough than did controls. There was also a significant increase in dyspnea among stainless steel welders compared with mild steel welders. The authors noted that similar findings have appeared in other studies, and have been associated with the chromium content of fumes from welding stainless steel. They concluded that a longitudinal study would be necessary to test the validity of this implied association.

Using questionnaires, Pirich et al. and Wolf et al. (Refs. 117 and 167) obtained data concerning respiratory symptoms, welding fume exposure, personal protective equipment used, specific welding processes used, and cigarette consumption from 64 welders and 102 non-welders who had been required by Austrian national labor laws to undergo spirometric examinations between 1992 and 1994. Statistical analysis of the data obtained by questionnaires and by pulmonary function tests showed that welding exposure was associated with a small, but significant, decline in MEF_{25} and only a borderline change in MEF_{50} . In comparison, smoking had a highly significant influence on both of these parameters. Declines in FVC, FEV_1 , and FEV_1/FVC found among welders were not statistically significant. The type of welding process used had no significant effect on any of the lung function measurements or on reported respiratory symptoms. The authors noted that their study lacked statistical power due to the small number of participants. They concluded that welding exposure could be part of the cause of the small observed decrease in MEF_{25} and the higher prevalence of respiratory symptoms in welders, but "...further studies are needed to define factors that make some workers more susceptible to the effects of chronic welding fume exposure than others."

Rocskay et al. (Ref. 124) examined the prevalence of respiratory diseases in 547 male ironworkers in Michigan who had been identified by their foremen as having been exposed to asbestos. All of the participants reported

having used welding and oxyfuel gas cutting equipment for an average of 5.7 years (range = 0.1 to 20.8 years). Union pension records were used to estimate the extent of asbestos exposure and years in the trade of each participant. Chest X-rays of the asbestos-exposed ironworkers revealed small irregular pulmonary opacities, pleural plaques, and pleural thickening (see Table 6). Rales were detected during physical examinations of 14% of the ironworkers and 25 to 35% reported having chronic cough, phlegm, and bronchitis. After correction for age and cigarette smoking, statistical analyses showed that the radiographic abnormalities, respiratory symptoms, and reductions in FVC, FEV₁, and FEV₁/FVC were significantly associated with years since joining the union, which the authors found to be the best measure of duration of experience as an ironworker. When compared with a group of male blue-collar workers from a study conducted by other investigators (Ref. 113), the ironworkers had a significantly increased prevalence of respiratory symptoms, which was independent of tobacco use. Because of imprecision in measures of exposure, the authors were not able to separate the contributions of asbestos, welding and cutting, and smoking to the increased incidence of respiratory disease observed among the ironworkers in this study.

Kennedy et al. (Ref. 80) and Teschke et al. (Ref. 144) measured personal exposures to cobalt and chromium and tested lung function in saw filers from eight lumber mills in British Columbia, Canada. The saw filers perform a variety of tasks associated with maintenance of the saws including welding or soldering, grinding, and sharpening of saw blade tips, and sharpening of chipper knives. The saw blades are made of hardened steel but the tips are composed of hard metal (an alloy of tungsten and 3 to 30% cobalt) or stellite (50% or more cobalt, and 30 to 35% chromium). The hard metal tips, which are soldered onto the saw blade, had been used in all of the

lumber mills for over 20 years. Stellite tips, which are joined to the saw blade by welding, were introduced more recently into the lumber mills because of their greater resistance to acids from cedar.

Personal air sampling and lung function tests were conducted with 112 workers who had worked in the lumber mill an average of 21.3 years where they were saw filers an average of 15.5 years. The saw filers reported that, at the time of the study, they worked more frequently with stellite tips than with hard metal tips, but the number of years they had spent working with hard metal tips was greater. Cobalt was detected in 62 of the 278 air samples, with a mean concentration of 9 µg/m³. Chromium was detected in 105 of the air samples, with a mean concentration of 4 µg/m³. Factors significantly associated with chromium exposure were working within 5 feet of a stellite welding operation, working within 5 feet of a saw steel heating operation, and grinding chipper knives which were composed of iron and 8–9% chromium. Cobalt exposures were positively associated with working within 5 feet of a hard metal, but not stellite, grinding machine.

A small, but significant, decline in FEV₁/FVC was found among saw filers who spent more than ten percent of their time in the current job welding stellite. An association between stellite welding and cough and nasal symptoms was attributed by the authors to chromium exposure. Mean cobalt exposure and duration of work involving hard metal wet grinding were significantly associated with reductions in FEV₁ and FVC. Even though the average cobalt exposures found by Kennedy et al. were about 5 µg/m³, well below the TLV of 20 µg/m³, there were significant decrements in pulmonary function tests among the saw filers who were exposed to cobalt.

Ozdemir et al. (Ref. 109) examined respiratory symptoms and lung function in 110 male welders from two companies in Ankara, Turkey. Arc welding and occasional oxyacetylene welding were performed for about 25 hours per week in confined spaces with poor ventilation, and without the use of respirators. Fifty-five male clerks from the same companies, with a similar distribution of age, height, and smoking habits, comprised the control group. The average duration of employment as welders was 16 years; 67 had been employed less than 20 years, and 43 had worked more than 20 years. No gross radiological abnormalities were seen in chest X-rays of any of the workers. The welders reported having respiratory symptoms more frequently than did the clerks, and the welders who smoked had more frequent symptoms than those who did not. Chronic bronchitis was significantly more frequent among welders (30%) than among controls (10.9%) and also among smoking welders compared with smoking controls. There were no

Table 6
Chest X-Ray Abnormalities Found
in Asbestos-Exposed Metal Workers

X-Ray Features	Number of Workers	Percent
Irregular pulmonary opacities	38	7.5%
Pleural abnormalities	105	20.7%
Pleural thickening	114	21.3%
Pleural plaques	100	18.7%
Pleural calcification	7	1.3%

General Note: Data from Rocskay, Ref. 124.

differences in the frequency of chronic bronchitis or in spirometric test values between groups of welders who had worked more than 20 years or less than 20 years. The FVC, FEV₁, PEF, and MEF₅₀ were significantly decreased in welders compared with the clerks, but there were no significant differences between welders who had never smoked and controls who had never smoked. The authors concluded that welders have an increased risk of chronic bronchitis and impaired lung function.

Ignjatovic et al. (Ref. 73) briefly described the results of physical examinations of 200 Serbian foundry workers, 200 welders, 70 spray-painters, and 60 controls. The foundry workers had the greatest incidence of chronic bronchitis, but the risk for the disease was also significantly elevated among the welders (21.5% vs. 11.25% among controls).

8.2 Occupational Asthma. Asthma is a debilitating chronic disease. It causes swollen and inflamed airways that are prone to sudden and violent constriction which can be life-threatening. The airway inflammation is initiated by immunoglobulin E (IgE) mediated allergic response to airborne substances. For poorly understood reasons, the incidence of asthma rose steadily in Westernized societies during the last century, and has doubled in the last 20 years (Ref. 35). Occupational asthma is caused by inhalation of specific sensitizing agents in the workplace and is distinguished from nonoccupational asthma by an older age of onset, the lack of seasonal variation in symptoms, and improvement of symptoms when away from work. According to Wegman and Fine (Ref. 161), the longer the workplace exposure before the onset of asthma and the longer the time after onset and before diagnosis, the poorer the prognosis. They noted that many patients with occupational asthma fail to improve, and over half must seek new jobs. The diagnosis of occupational asthma is accomplished using comprehensive histories of occupational exposures and symptoms. If there is doubt about the diagnosis, immunological tests and bronchial challenge with the suspected workplace agents may be used. A drop in peak expiratory flow rate (PEFR) or substantial diurnal variability in peak expiratory flow on work days, but not on days away from work, supports a diagnosis of occupational asthma (Ref. 95). Several studies used the methods of epidemiology to document and analyze the incidence of asthma and other respiratory diseases in populations of welders and to compare the incidence of respiratory disease between groups. The features of the different types of studies used, the methods for calculating relative risks for each type of study, and factors affecting the accuracy of risk estimates in occupational epidemiology studies are summarized in the box below.

Having observed airways obstruction and asthma among welders in their clinical practice in Northern England,

Beach et al. (Refs. 13 and 14) conducted a study of the prevalence of asthma in welders compared with other shipyard workers. Subclinical respiratory changes which may be predictive of asthma were measured in young workers. The 1024 subjects of the study were male shipyard employees who had started as apprentices between 1980 and 1987 and were completing 3, 5, 7, or 9 years of employment in various trades. Controls were 15- to 17-year-old applicants for apprenticeships in the shipyard. Occupations were ranked according to their exposure to airborne contaminants: high (welders and caulker/burners), ambient (other shop floor trades such as plumbers, lathe operators, electrical workers, and sheet metal workers), and negligible (office workers). Only those men with no history of asthma and no spirometric evidence of asthma in a pre-employment physical examination were included in the study. Skin prick tests for four common airborne allergens were administered to each participant to determine the presence of atopy, and airways responsiveness was determined by measuring the provocative dose of methacholine necessary to produce a 20% decrease in FEV₁ (referred to as the PD₂₀). Although, in the authors' clinical experience, active asthma is usually associated with a PD₂₀ less than 200 µg of methacholine and almost never found in those with a PD₂₀ greater than 1000 µg, a PD₂₀ of 6400 µg methacholine was taken as a positive test for airways reactivity.

Personal air samples were collected during the morning and afternoon workshifts in the breathing zones of six different subjects each day during ten one-week periods in 1989 and 1990. Concentrations of total fume, nickel and chromium measured in samples collected from mild steel welders, pipe welders, caulker/burners, and the two comparison groups are shown in Table 7. Total fume concentrations in air samples collected from mild steel welders and caulker/burners were significantly higher than those collected from pipe welders or the ambient exposure group. Nickel concentrations were significantly higher in samples collected from the caulker/burners than in those collected from the other workers in the high and ambient exposure groups, but mean chromium concentrations did not vary significantly among samples collected from any of the workers in the high and ambient exposure groups.

The airways responsiveness data were analyzed for the effects of years of experience for each of the exposure groups, controlled for age, smoking, and atopy. Plots of the changes in PD₂₀ with years of employment are shown in Figure 3. The average PD₂₀ increased by 15% annually in the negligible exposure group and by 2% annually in the ambient exposure group, showing a significant trend towards decreased airways responsiveness with time in these two groups. The average PD₂₀ decreased by about 2% annually in the mild steel welders.

OCCUPATIONAL EPIDEMIOLOGY

Epidemiology is the study of the comparative frequency of a disease in different populations. **Endpoints** in the studies may be **incidence** of disease or **mortality** from it.

Occupational epidemiology is the study of the occupational environment as a risk factor for disease in groups of workers. It has the **advantages** of good documentation of exposure from individual work records and often groups of control subjects can be chosen from within the same plant. The major **disadvantage** is that working populations are usually healthier than the general population. This phenomenon is referred to as **the healthy worker effect**.

A **cohort study** is a **longitudinal** study of the occurrence of a disease over time. It may be **retrospective**, in which case the exposure and incidence data are **historical**. A major disadvantage of a **retrospective** study is that exposure data are usually incomplete. A **prospective** study is undertaken in real time and has the advantage of better control of the experimental variables and the ability to measure exposure. It has the disadvantages of high cost and time delay. Both types of **cohort** studies require large **populations** of workers (thousands of person-years of exposure) in order to have a reasonable chance of detection of disease, particularly diseases such as lung cancer which are not rare in the general population.

Risk ratios are the means of reporting the outcomes of cohort studies. **Relative risk (RR)** is the ratio of the incidence rate of disease in the population studied (for example, welders of stainless steel) and that of another population not exposed in the same way (for example, welders of mild steel, or nonwelders in the same factory). When the incidence of disease in welders is compared with incidence statistics for the general population, the ratio is called the **standardized incidence ratio (SIR)**, and the **standardized mortality ratio (SMR)** is calculated from mortality data in the same manner.

In **case-control studies**, also known as **case-referent studies**, of a particular disease, a population with the disease (**cases**) is matched with a population without the disease (**controls** or **referents**). The **odds ratio (OR)** for the disease is calculated from the ratio of cases who are in the occupational group or groups being studied (such as welders) divided by the ratio of controls in the same populations. For example:

$$\text{OR for lung cancer} = \frac{\% \text{ cases who are welders}}{\% \text{ controls who are welders}} .$$

Case-control studies cannot provide an estimate of the true frequency of a disease in the population studied. They have the advantages of small sample size, and relatively low expenditure of money and time. A major disadvantage is that the information about the **control group** may be incomplete.

Selective migration, movement of persons adversely affected by an industrial environment to a less hazardous one, may combine with the **healthy worker effect** to bias the results of occupational epidemiology studies.

Confounding is distortion due to mixing of the exposure being studied with extraneous risk factors. **Confounders**, or **confounding factors**, are both **independent** and **correlated** with the occupational factors being studied).

Controlling for **confounders** may be accomplished by **restricting** the population under study (for example excluding smokers or workers who have been exposed to asbestos) or, especially in **case-control** studies, by **matching** the frequency of the **confounders** in the **controls** with that in the occupational group being studied. **Risk ratios** may also be adjusted for known effects of **confounders** when exposures to them are not consistent across groups.

Statistical analyses are applied to all of the **risk ratio** calculations to develop a **95% confidence interval (#CI)**. When the upper and lower boundaries of the **CI** are both greater than one, there is a **statistically significant** finding of a greater risk for the disease among the group under study than among the **controls**.

Adapted from Shy (Ref. 130)

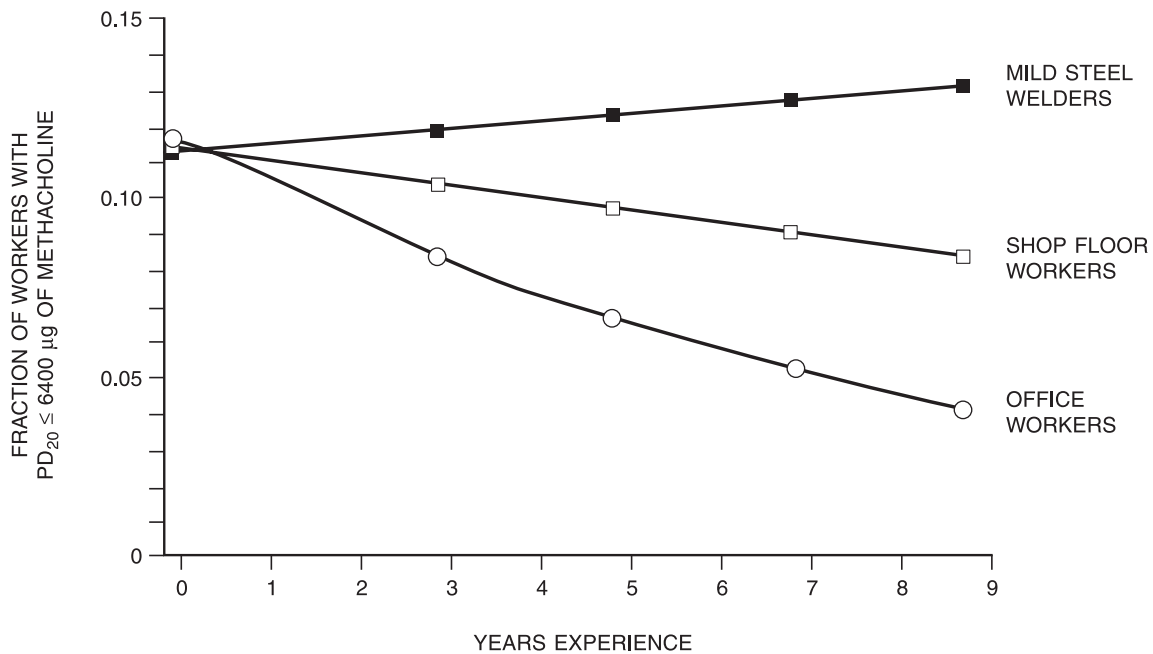
Table 7
Welding Fume Exposures in a British Shipyard:
Mean Exposures (95% Confidence Intervals)

Exposure Group	MS ⁽¹⁾ Welder	Pipe Welders	Caulker/Burners	Ambient	Negligible
No. of subjects	269	31	78	40	8
Total fume $\mu\text{g}/\text{m}^3$	1.81 (1.61–2.03)	0.97 (0.73–1.30)	2.76 (2.1–3.60)	0.92 (0.60–1.41)	0.21 (0.09–0.48)
Chromium $\mu\text{g}/\text{m}^3$	4.69 (4.01–5.48)	5.42 (4.11–7.13)	6.56 (4.82–8.93)	3.97 (2.88–5.49)	0.57 (0.09–3.58)
Nickel $\mu\text{g}/\text{m}^3$	4.10 (3.32–5.05)	6.56 (4.66–9.22)	15.96 (12.4–20.5)	3.28 (1.52–7.10)	0.10 (0.01–0.80)

General Note: Data from Beach et al., Ref. 14.

Note:

(1) MS = Mild Steel.



General Note: Data from Beach et al., Ref. 13.

Figure 3—Changes in Airways Responsiveness During the First 9 Years of Experience in the Trade for Mild Steel (Regular) Welders, Shop Floor Workers, and Office Workers

The change in airways responsiveness with time among mild steel welders was statistically significant when compared with the negligible exposure group. Airways responsiveness among pipe welders and caulker/burners did not change significantly with time compared with the negligible exposure group. A dose-response relationship was shown between the total fume concentrations and changes in PD₂₀ when pipe welders and caulker/burners were not included in the analysis, but changes in the airways responsiveness did not correlate with the concentrations of any of the metals measured in the personal air samples. Beach et al. concluded that the subclinical

changes in lung responsiveness that were found among welders in this study may be important signs of a progression towards clinical asthma. They estimated, from the annual changes in PD₂₀, that about 1% of the mild steel welders were likely to develop symptomatic asthma after 5 years of work. Smoking and high levels of atopy have effects of the same magnitude and are additive.

As part of the “European Community Respiratory Health Survey,” Kogevinas et al. (Ref. 84) examined the prevalence and causes of occupational asthma in five areas of Spain. A random sample [number of subjects (n) = 16,884] of the total population of that area, 20 to

44 years of age, was asked to respond to seven questions concerning respiratory symptoms. A subsample of 3310 randomly-chosen individuals was selected from the population sample. A second subsample consisted of the 1032 subjects in the population sample who had reported asthma-related symptoms and had not been included in the first subsample. A total of 2646 individuals from both subsamples who responded to a long questionnaire detailing occupational history constituted the population for the occupational asthma study. Five definitions of asthma were used, and individuals from the study population made themselves available for different examinations for asthma. When compared with a group of professional, administrative, clerical, and service workers, the occupational set of welders, solderers, and electronic assemblers showed an increased risk of asthma as defined by reports of wheezing or whistling in the lungs, but this was not statistically significant. A test for airways reactivity to methacholine (PD₂₀) was performed on 1797 subjects. The inclusion of bronchial reactivity, as measured by the PD₂₀, weakened the association of asthma with the occupational set of welders, solderers, and electronic assemblers. When asthma was defined as having had an attack of asthma or shortness of breath during the last 12 months or as currently taking asthma medication, there was a significantly greater risk for the disease in the group of welders, solderers, and electronic assemblers (Odds Ratio or OR = 2.70, CI = 1.01–7.21). The inclusion of solderers and electronic assemblers, who are exposed to reactive organic chemicals, in the same group with welders, makes it difficult to interpret these results in terms of the actual risk for asthma in welders.

Meredith and Nordman (Ref. 98) described and evaluated registries maintained in four countries that can be used for tracking the incidence of occupational asthma. The registries considered were: in Finland, the register of all cases of occupational asthma maintained by the Finnish Institute of Occupational Health (FIOH); in the United Kingdom, the projects Surveillance of Work-related and Occupational Respiratory Disease (SWORD) to which newly-diagnosed cases of work-related respiratory disease are reported and SHIELD, a more intensive survey of occupational asthma undertaken in the West Midlands area of England, which includes reports from the local medical board as well as cases reported by chest and occupational physicians; in Canada, reports of successful new claims for compensation in the province of Quebec; and in the U.S., the Sentinel Event Notification System for Occupational Risks (SENSOR) which has been in operation since 1988 in four states (Colorado, Massachusetts, Michigan, and New Jersey). The SENSOR program emphasizes the identification of sentinel cases for the purpose of investigation and prevention, rather

than for obtaining an epidemiological overview of the distribution and determinants of disease in the population. The authors judged the Finnish data base to be the most complete. All employees and self-employed farmers are covered by the national workers compensation insurance network, and all claims for, and diagnoses of, asthma are required to be reported to the government. Because of their voluntary nature, the other data bases suffered from under-reporting of cases. Occupational information was available only in the Finnish FIOH and British SWORD and SHIELD registries.

In the Finnish registry, the category of “welder/solderer/electronic assembler” had 1,035 cases of occupational asthma per million man-years (CI = 698–1477), 6.8 times the rate among all employed persons in the data base (152 per million, CI = 137–168). The reported rates of asthma in the SWORD and SHIELD databases were much lower than those in the FIOH among all occupations studied, but the relative incidence among the group of welders, solders and electronic assemblers was still significantly greater than the incidence among all occupations surveyed.

Flodin et al. (Ref. 52) conducted a case-referent study of bronchial asthma related to workplace exposures in two adjacent communities in Sweden where wood dust exposure from furniture and prefabricated home manufacture was common. Questionnaires were sent to 182 residents of the two communities who were receiving prescription medication for asthma. The 79 responders who met the American Thoracic Society criteria for asthma and had contracted asthma after the age of 20 were selected as the study subjects. The 472 referents were drawn at random from the same community as the subjects. Four referents were matched to each case by age, gender, and municipality. Occupations were grouped into four classes on the basis of descriptions given by the subjects about their workplace exposures to airborne contaminants. Welding was in the most highly-exposed category. Belonging to this category, which comprised 56 job titles, was found to be a significant risk indicator for bronchial asthma (OR = 3.2, CI = 1.6–6.3). Controlling for smoking or introducing a lag time of one year after exposure had no effect upon the odds ratio (OR).

Simonsson et al. (Ref. 131) briefly scribed preliminary results of a prospective study of bronchial responsiveness in 185 male and 17 female nonasthmatic Swedish workers during the first 3 years of their employment. All of the subjects had jobs in which they were exposed to substances potentially harmful to the respiratory tract, and 65 of them were exposed to welding fumes. The control group consisted of 49 male food industry workers. Lung function tests and blood tests were administered to all of the participants. Significant decrements

in the area under the FEV₁ curve were found among welders compared with controls. These decrements were significantly related to the duration of the welding experience and to the development of asthma. Atopy, serum concentrations of IgE, and the results of the standard lung function tests FEV₁, FVC, and FEV₁/FVC were not significantly related to the presence of asthma. The authors concluded that welding fumes seem to be a cause of asthma and increased bronchial reactivity.

Toren (Ref. 148) examined rates of self-reported cases of occupational asthma among different occupations in Sweden. The number of cases recorded from 1990 to 1992 was obtained from the Swedish register of reported occupational diseases. All cases were classified according to occupation. Reported incidence rates were calculated by comparing the number of asthma cases reported to the register in each job category with the number of persons from the general population employed in the same job categories, as recorded in the 1990 national census. The highest rates were reported, in descending order, by male bakers, furnacemen, male welders, female chemical and plastic production workers, and female poultry and dairy farm workers. The reported incidence rate (647 per million, CI = 474–820) among male welders aged 20–64 was seven times greater than that of the working male population (91 per million, CI = 84–98). The self-reported asthma rate was slightly higher when only younger welders were considered; the reported incidence rate (690 per million (CI = 476–904) among male welders, aged 20–44, was nine times higher than that of the working male population (91 per million, CI = 84–98). The number of female welders was too small for them to be included in this analysis. The author noted that while surveys of self-reported disease cannot reach the accuracy of those using clinical diagnoses, this information provides a measure of asthma which can be used to form hypotheses or to strengthen confidence in similar findings among occupational groups in other studies.

Devereux et al. (Ref. 42) investigated the role of dietary sodium in the etiology of asthma, which has been a controversial issue for some time. The study population included 1059 English shipyard workers who had been exposed to welding fumes and 587 men selected at random from family practitioner registers in two areas of England. All of the shipyard workers were subjected to spirometry, methacholine challenge, and skin prick tests to determine atopy. Each participant with a positive methacholine test (PD₂₀ equal to or less than 6400 µg methacholine) was requested to provide a 24-hour urine sample, as were matched controls from the same occupational subgroup who had not shown a PD₂₀ less than 6400 µg methacholine. Sodium excretion was significantly higher among the shipyard workers who had been exposed to welding fumes, but statistical analysis

showed no relationship between sodium excretion and the response to the methacholine challenge in either the shipyard workers or the controls. The authors concluded that if a relationship exists between airways responsiveness and dietary sodium, it is unlikely to be strong.

Khoo (Ref. 81) described a case of occupational asthma in a 36-year-old male arc welder who worked in a shipyard in Singapore. After three months of using GMAW daily during a 12-hour shift, he developed wheezing attacks. He was treated at a hospital emergency room and was then referred to the shipyard clinic. There, rhonchi (bronchial chest sounds) were heard during clinical examination, and the patient was treated with bronchial dilators. Over the next four years, the patient was treated for asthma with increasing frequency at the shipyard clinic and by private and public health physicians. Asthma attacks usually occurred during the patient's sleeping hours. Four years after the initial complaint, spirometric tests were performed at a time when the patient was symptom-free. His FEV₁, FVC, and PEFR were all just 60–65% of predicted values. To confirm that the asthma was related to welding, measurements of PEFR were taken daily for 18 consecutive days: 5 days without exposure to welding, followed by 7 days of welding, and 6 days away from welding. His mean PEFR declined during the week of welding and recovered during the week after he ceased welding.

Torres (Ref. 149) treated a 24-year-old female U.S. Air Force sergeant who had developed progressively more severe symptoms of shortness of breath, nonproductive cough, and tightness in the chest during the previous four months. Her symptoms usually appeared in the late afternoon or early evening. They often resolved in the morning, and they also improved during weekends and vacation periods. She had been working as a welder for the past year, using solders and fluxes on a daily basis. A chest X-ray proved normal. Pulmonary function tests at the time of presentation indicated a mild obstructive pattern which normalized following bronchodilator therapy. A subsequent methacholine responsivity test showed markedly increased bronchial airway hyperresponsiveness, confirming the diagnosis of asthma. The patient was removed from the welding environment and, two months after cessation of exposure, she was asymptomatic and had normal pulmonary function, although she still displayed bronchial hyperresponsiveness in the methacholine challenge test.

Vandenplas et al. (Ref. 153) examined a 21-year-old man who had developed asthma after working for three months in a manufacturing plant, performing GMAW with an argon-CO₂ shielding gas on un-coated mild steel. He had previously worked for a year welding iron using SMAW, without experiencing respiratory symptoms. When he used GMAW, his symptoms (chest tightness,

wheezing, and cough) appeared by the end of the work shift on Mondays, progressed throughout the work week, and subsided over the weekend. Treatment with inhaled medications proved ineffective, and the worker quit welding 4 months after first reporting symptoms. He was examined by the authors 8 months after that time, when he was still experiencing asthmatic symptoms during exercise but was not regularly taking medications. The subject had no history of atopy, and skin prick tests to common allergens and salts of nickel, zinc, copper, and manganese produced negative results. Spirometric evaluation showed that his FEV₁ was normal, but the FEV₁/FVC ratio was 79% of the predicted value. The investigators set up a welding test facility in the hospital workshop and exposed the subject to welding fumes from GMAW of mild steel for 2 hours on each of 2 consecutive days. Eight hours after the first exposure, he showed a 26% fall in FEV₁. On the second day, he had an immediate 23% decrease in FEV₁ and an additional decrease of 25% 8 hours later. One week after that the subject welded mild steel using SMAW for 2 hours and did not develop significant changes in FEV₁. The welding fumes from the GMAW exposure, measured using a personal sampler mounted on his shoulder, had a total of 2.1 mg/m³ of respirable particles, and the concentrations of iron (994 µg/m³), manganese (144 µg/m³), and copper (30 µg/m³) were below the TLVs. Chromium, nickel, and cobalt were all below detectable levels. Ozone concentrations ranged from 0.06 to 0.16 ppm, but specific inhalation challenge with ozone did not result in significant changes in the subject's FEV₁, with or without provocation with histamine. Two control asthmatic subjects were subjected to the GMAW exposure regime without developing bronchial reactions. The authors could not identify the specific causative agent in the complex welding aerosol, but they concluded that the asthmatic reactions in the welder were specifically related to the GMAW procedure and that ozone was excluded as the causative agent.

8.3 Other Allergic Respiratory Tract Conditions.

Using insurance claim records, Baur (Ref. 12) examined the incidence of occupational asthma and other allergic respiratory tract conditions in workers in western Germany. He found that reported cases of allergic airways disease had risen rapidly in the decade prior to 1992, but they appeared to plateau in 1993. Allergy-related conditions were most common in the food industry. In 1993, 41 new cases were confirmed in the German metal working industries. Welders and cutters accounted for 25 of them. Isocyanates and acid anhydrides were the other major exposures related to allergic airways disease. Baur noted that epidemiological investigations are needed to provide the information necessary for causal analysis and development of preventive strategies.

Also known as allergic alveolitis, hypersensitivity pneumonitis (HP) is a complex phenomenon characterized by inflammation in and around the tiny air sacs (alveoli) in the lungs caused by an allergic response to inhaled allergens or antigens (materials that can sensitize individuals and induce an immune response). Yoshida et al. (Ref. 169) studied 835 cases of HP in Japan related to occupation. Of 115 cases that could be related to occupational exposures, welding was implicated in four. The vast majority of the occupational cases were among agricultural workers exposed to various microorganisms and spores.

8.4 Respiratory Symptoms. Welch et al. (Ref. 162) investigated the pathogenesis of occupational rhinitis (inflammation of the nasal mucous membranes) by studying the characteristics of nasal symptoms in 100 former English shipyard workers with this condition. All of the workers had been exposed to welding, burning, and paint fumes, as well as to dust and particulate matter from grinding for at least 10 years, while working in the enclosed spaces between the double bottoms of ships. They were given nasal examinations and were tested to determine if there was any loss in the sense of smell. The great majority of the rhinitis sufferers had nasal obstruction, nasal crusting, and rhinorrhea (discharge of watery mucus). Less frequent symptoms were bleeding, chronic sinusitis, and nasal polyps. Partial loss of the sense of smell was experienced by 42%, and anosmia (total loss of sense of smell) by 10% of the rhinitis patients. The authors concluded that shipyard workers probably suffer from occupational rhinitis, and that there are several potential mechanisms for the pathogenesis of this condition. They hypothesized that the effects of chronic irritation of the nasal mucosa by airborne agents may be compounded by chemical sensitivity and subsequent allergic responses and may be cumulative, rendering the mucosa sensitive to further chemical or dust exposure and physical stimuli.

Radenbach examined 30 male welders who were referred to a clinic in Grosshansdorff, Germany with symptoms including cough, copious phlegm, and shortness of breath during rest or exercise (Ref. 120). They had welded for an average of 19.5 years. Fifteen were smokers, 11 were ex-smokers, 20 had shipyard experience, 10 had worked in unventilated enclosed spaces, at least three had welded coated or painted surfaces, and 15 had suspected or documented exposure to asbestos. The following correlations were seen between exposures and symptoms: shortness of breath with duration of welding exposure and shipyard work; welding of coated parts with increased cough and phlegm production and a decline in FEV₁; use of chrome-nickel electrodes with an increased incidence of bronchial hypersensitivity, but with less frequent cough; and dry cough or rales with working in confined spaces. Asbestos exposure and use of coated electrodes were not significantly associated

with any of the symptoms or lung measurements. Welders in shipyards and repair plants had the greatest incidence of the symptoms studied and also the greatest decrements in lung function.

8.5 Pulmonary Hypertension. In some cases of slowly developing respiratory failure, pressure in the blood vessels throughout the lungs increases. This condition, called pulmonary hypertension, can damage the blood vessels, impairing oxygen transfer, and stressing the heart. Polyakov et al. (Ref. 118) examined nine Russian welders, aged 35–45, with a mean welding experience of 21.3 years. All of the welders reported an occasional dry cough. Their lung function tests and pulmonary diffusing capacity as measured by the DLCO were normal. Chest X-rays revealed pneumoconioses in four of the welders. The pulmonary arterial pressure in these four welders was normal, but it was increased in the welders who had normal X-ray patterns. From this limited study, the authors concluded that long-term inhalation of welding fumes may be a cause of primary pulmonary hypertension.

8.6 Pneumoconiosis. While siderosis is not usually associated with disease processes such as fibrosis or loss of pulmonary function, such cases are occasionally reported to have occurred after long-term exposure to welding fumes. In 1996, Roesler et al. (Ref. 125) described the case of a welder with interstitial lung fibrosis that they attributed to iron deposits in the lungs. The man was 44 years old and had worked as a welder since the age of 17. Most of his work had been done in confined spaces with inadequate ventilation and no respiratory protection. At age 25, he was diagnosed with tuberculosis. Treatment was successful and, after some time, chest X-rays showed no signs of disease. At age 27, chest X-rays showed siderosis, but he had no respiratory symptoms. As the pneumoconiosis progressed, he eventually suffered a reduction in pulmonary function. At the age of 44, his condition was diagnosed as a restrictive ventilatory disorder with a reduced diffusion capacity. Histologic examination of biopsied lung tissue showed iron deposits in close proximity to fibrotic areas. The investigators concluded that siderosis had progressed into interstitial pulmonary fibrosis. They attributed his condition to continuous exposure to welding fumes in poorly ventilated work areas. It is also possible, however, that other factors, such as his early tuberculosis, may have contributed to the development of fibrosis.

In a clinic in the Czech Republic, Spacilova (Refs. 137 and 138) followed the progress of 111 welders over a period of 1 to 30 years (average 10 years) who had chest X-ray abnormalities or respiratory complaints. The welders had an average of 25 years work experience at the time of the first examination. The X-ray changes regressed in 15 of the 42 of patients who had completely stopped weld-

ing during the 10-year follow-up period. Fibrosis of uncertain etiology was observed in the lungs of seven of the patients. The number of patients with chronic bronchitis increased from 27 (24%) to 47 (42%) during the 10-year follow-up period.

Akira (Ref. 1) used computed tomography (CT) to characterize the radiographic features of pneumoconioses resulting from exposure to welding fumes, hard metal, aluminum, or graphite dusts. CT scans of 48 male patients (21 welders plus 19 graphite, 6 aluminum, and 2 hard metal workers) with a history of radiographic lung changes were reviewed. The patients were referred to the study because their chest X-rays were suggestive of pneumoconiosis. They had a mean age of 59 years and a mean duration of occupational exposure to dust and fumes of 20 years. Only five of the patients had never smoked. Twenty-nine patients had respiratory symptoms including difficulty breathing and coughing with excess sputum production. The CT findings were confirmed by histological examination of lung biopsy specimens from 22 of the patients.

The CT patterns showed characteristic features for each of the occupational exposures. The poorly defined micronodules found in the arc welders were shown by histologic examination to consist of accumulated iron particles that had been engulfed by macrophages. These micronodules were not areas of active fibrosis. In contrast, fibrosis was noted in CT scans of five of the six patients exposed to aluminum dust. Akira noted that prior tuberculosis may have been responsible for the fibrosis in two of these patients. CT findings in the hard metal workers were consistent with the interstitial pulmonary fibrosis associated with the disease caused by exposure to hard metal. Akira noted that while CT may not be suitable for routine occupational screening, it is more sensitive than chest X-rays in depicting the lung abnormalities associated with various forms of pneumoconiosis and could be of value in case detection and characterization.

Park et al. (Ref. 110) compared the proliferation of opacities in chest X-rays and pulmonary function in Korean shipyard welders and coal miners with pneumoconiosis. No correlation was seen between FVC and the severity of the pneumoconiosis in either group. FEV₁ decreased significantly with the profusion of small, regular opacities in the coal miners' lungs but was only decreased in the more advanced cases of pneumoconiosis in welders. The FEV₁ and FVC did not differ significantly between smokers and nonsmokers in either group.

9. Cancer

9.1 Lung Cancer. In 1990, after reviewing the available literature, the International Agency for Research on Cancer

concluded that welding fumes are “possibly carcinogenic to humans.” This finding was based on limited evidence in humans and inadequate evidence in animals (Ref. 74). Several studies performed since then have indicated that men exposed to welding fumes in their daily work have a greater risk of developing lung cancer when compared with workers in other occupations or the general public. There is, however, no general agreement concerning how much of the excess risk is due to welding fumes, which components in the welding fume could be responsible for the excess risk, and whether a large part of the risk can be attributed to factors such as smoking and asbestos exposure. Although components of stainless steel, notably nickel and hexavalent chromium [Cr(VI)] have been identified as carcinogens, the recent research has not consistently shown a greater risk of lung cancer among welders of stainless steel compared with those who welded only mild steel. Some of the research discussed below addressed these concerns. Explanations of the terms used to describe the design of cancer studies described below can be found in the epidemiology box in 8.2.

Hansen et al. (Ref. 62) conducted a retrospective study of the incidence of cancer in a cohort of male welders, grinders, and other metal workers in 79 stainless steel welding companies and five mild steel welding companies in Denmark. All of the workers were born before 1965 and had been employed as metal workers for at least 12 months between April 1964 and December 1984. A total of 28,164 workers met these criteria, and consultation with managers and supervisors identified 10,059 who had worked in welding departments. In 1986, all members of this cohort were traced: 9,114 were alive and living in Denmark, 812 were deceased, and 133 had emigrated. Questionnaires on lifetime occupational exposure and smoking/drinking habits were sent to living members of the cohort and to surviving spouses and colleagues of deceased or emigrated subjects. This effort yielded 8,372 responses suitable for analysis. Years spent in each type of welding, years exposed to stainless steel grinding and asbestos, and smoking habits were obtained for each individual in the study and categorized by a method which accounted for the many individuals who had changed their exposure classifications during the 20-year study period.

Because the Danish Cancer Registry is virtually complete and is linked to personal identification numbers, all diagnoses of cancer for the individual workers in the study could be identified and aligned with their exposure histories. Standardized incidence ratios (SIR) were calculated by comparing the cancer incidence among the study population, and various exposure groups within it, with the expected number of cancers from the Danish Cancer Registry, based on national cancer incidence rates

for all types of cancer. A 31% increase in the incidence of lung cancer was found among all welders (SIR = 1.31), but this finding was not statistically significant (CI = 0.99–1.71). The lung cancer incidence data were further analyzed by category of exposure. Significantly elevated risks for lung cancer were found among groups: “ever employed in a welding company” (SIR = 1.51, CI = 1.24–1.83), “ever employed as a welder of any type” (SIR = 1.38, CI = 1.03–1.81), and “nonwelding metal worker” (SIR = 1.69, CI = 1.23–2.26). A link between length of employment in the welding industry and risk of lung cancer could not be established. A nonsignificant 45% excess of lung cancer and a statistically significant excess of testicular cancer (4 cases, SIR = 5.53, CI = 1.51–14.16) were found among grinders of stainless steel. There were no major differences in smoking habits between job groups. Hansen et al. concluded that their data suggest an association of welding of mild steel and possibly stainless steel with an increased lung cancer risk. An increased risk of the same magnitude was found among nonwelding metal workers.

Lauritsen and Hansen (Ref. 90) conducted a case-referent study of lung cancer mortality using the same cohort of metal workers that was examined in the study by Hansen et al. (Ref. 62) described above. The study population consisted of the 675 members of the cohort who had died between April 1968 and December 1985. The cases were the 94 subjects who had died of lung cancer. The 439 referents were those who had died of other causes, excluding those who had died of non-malignant respiratory diseases and those who were younger than the youngest lung cancer case. Estimates of lifetime occupational exposure and smoking/drinking habits for this deceased population were obtained from surviving spouses and colleagues. A significant increase in lung cancer mortality was associated with exposure to asbestos for more than ten years. Having ever welded was associated with a statistically significant 70% increase in lung cancer risk (OR = 1.7, CI = 1.0–2.8). Lung cancer mortality was significantly associated with up to 15 years exposure to welding fumes but, in welders with more than 15 years experience, the odds ratios for lung cancer were not as large, and the differences between welders and nonwelders were no longer significant. The authors noted that this last finding weakens the perceived link between welding exposure and lung cancer, but they suggested that it may be a result of self-selection of unhealthy welders out of the welding population. The authors planned to continue the study of this cohort with emphasis on the effects of the duration of exposure and the latency between initial exposure and the development of lung cancer.

In a study designed to evaluate the reliability of exposure estimates used in the two studies of Danish metal

workers described above (Refs. 62 and 90), Hansen (Ref. 61) obtained occupational exposure and smoking information from spouses and colleagues of the 118 members of the cohort of Danish welders who had died between August 1986 and August 1988, and compared it with information that had been provided by these workers before they died. He found a high level of concordance between the two sets of data for most of the occupational exposures and for smoking habits. Analysis of bias showed that several exposures were substantially underestimated by each of the surrogate sources. The author noted that each of the subjects had died within two years of the interview with his spouse or colleagues, while the decedents in the original cohort had died over an 18-year period. The difference in recall period might well have influenced the accuracy of the surrogates' reports.

Danielsen et al. (Ref. 38) conducted a historical prospective cohort study of the incidence of cancer among Norwegian boiler welders. Information concerning date of onset of welding, method of welding, and alloys welded was available from a national registry. The cohort consisted of 2,957 electric arc welders, of whom 606 had welded stainless steel. Up until 1970, the primary welding method was SMAW; after that the use of GMAW and GTAW gradually increased. There was no information on individual smoking habits. Asbestos exposure was common among boiler welders up until the mid-1970s. The Cancer Registry of Norway was used to determine the number of cases of cancers of all types among the welders. These were compared with age-specific incidences for Norwegian men for each calendar year from 1953 to 1992. Observed and expected cases for the first 15 years of exposure were excluded in an attempt to account for the lag time between initial exposure and the development of cancer.

An increased risk for lung cancer was found in the entire cohort of welders, but it was not statistically significant (SIR = 1.33, CI = 0.99–1.76). For stainless steel welders, the relative incidence of lung cancer was not elevated (SIR = 1.03, CI = 0.38–2.26). A significant increase in kidney cancer was observed among the entire cohort of 2957 welders (SIR = 1.78, CI = 1.07–2.78), but this was smaller and nonsignificant in the subcohort of 606 who had ever welded stainless steel (SIR = 1.18, CI = 0.12–4.24). The authors concluded that welders may have a small excess risk of lung cancer, which could not be attributed to the cohort of stainless steel welders. They asserted that the specific effect from exposure to welding fumes is “disputable,” and that confounding factors such as asbestos exposure and smoking probably account for a major part of the excess risk.

In 1994, Sjogren (Ref. 133) conducted a meta analysis in which the data from five studies of lung cancer among welders of stainless steel (including one by Moulin) were

combined and concluded that there is a statistically significant relationship between stainless steel welding and lung cancer. In a letter to the editor, Moulin (Ref. 99) disputed this conclusion. He cited several large studies, particularly one (the nine nation historical European cohort study) which included 11,092 welders from eight countries, which found no consistent differences between mild steel and stainless steel welders, and cited asbestos exposure and smoking, plus the healthy worker effect, as confounding factors.

Then, in a meta-analysis of his own, Moulin (Ref. 100) combined results from 36 independent studies, which had included 49 determinations of relative risks for lung cancer among different groups of welders, expressed in terms appropriate for the various experimental designs [i.e., odds ratios (OR) from case-control studies, standardized mortality ratios (SMR) from mortality studies, and standardized incidence ratios (SIR) from cancer incidence studies]. Moulin's methodology allowed all these results from studies using different designs to be combined to create larger populations and achieve more powerful statistical relationships for the analysis of relative risk. Since the various measurements and estimates of exposure could not be combined, dose-response relationships were not addressed. The results of Moulin's analysis, grouped according to welding category and type of study, are summarized in Table 8. In all welding categories and in all types of studies, there was a statistically significant elevated risk for lung cancer compared with the respective population or control groups. The combination of “all or unspecified” types of welding produced a relative risk of 1.38. The assumed greater exposure to asbestos among shipyard welders as compared with nonshipyard welders did not result in a greater relative risk for lung cancer. The combined relative risks were the same for welding mild steel and for welding stainless steel. According to Moulin, the observed excess incidence of lung cancer among welders may be a combination of the effects of asbestos exposure and smoking with those of welding.

Finkelstein (Ref. 50) conducted a case-control study of the association between occupation and lung cancer in two Canadian cities, Hamilton and Sault Ste-Marie. Cases were all male residents between 45 and 75 years old who had died of lung cancer between 1979 and 1988. The 967 cases and their occupations were identified from death certificate records. They were matched by age, year of death, and city of residence with 2821 controls who had died from other causes. A statistically significant increased risk for lung cancer was found among all construction workers when they were compared with industrial workers (RR = 1.38, CI = 1.06–1.79). There was only a slight, nonsignificant increased risk for lung cancer among welders (RR = 1.07, CI = 0.57–1.91). Using

Table 8
Results of a Meta-Analysis of Lung Cancer in
Welders Combined Relative Risks (RR) from 36 Studies

Welding Categories	No. of Studies	Observed Cases	Combined RR	95% CI
All or unspecified	19	1028	1.38	1.29–1.48
Population-based studies	7	585	1.39	1.28–1.51
Case-referent studies	9	230	1.72	1.36–2.18
Cohort studies	3	213	1.27	1.10–1.46
Shipyard welding	14	305	1.30	1.14–1.48
Case-referent studies	6	144	1.16	0.92–1.47
Cohort studies	8	161	1.36	1.17–1.60
Nonshipyard welding	7	173	1.35	1.15–1.58
Case-referent studies	1	13	3.80	1.40–10.7
Cohort studies	6	160	1.31	1.12–1.54
Mild steel welding	4	137	1.50	1.18–1.91
Case-referent studies	2	58	1.56	0.82–2.99
Cohort studies	2	79	1.49	1.15–1.93
Stainless steel welding	5	114	1.50	1.10–2.05
Case-referent studies	3	87	2.00	1.22–3.28
Cohort studies	2	27	1.23	0.82–2.05

General Note: Data from Moulin, Ref. 100.

these data, Finkelstein calculated that there should have been 24 lung cancer deaths among welders in Ontario in 1980–1989, but only eight claims were submitted to the Ontario Workers' Compensation Board, and only four of these were accepted. Similar discrepancies were found in other occupations between the calculated number of lung cancer deaths and the number of claims for compensation made and accepted. The author concluded that only a small fraction of cases of occupationally-related lung cancer are compensated. He suggested that physicians be alert to the recognition of occupational illness and act as advocates for patients who have developed them.

Caroyer et al. (Ref. 28) made similar observations in Belgium. They surveyed occupational cancers among the 371 male workers who received disability compensation in Belgium for cancer diagnosed between January, 1979 and December, 1986. Of the 30,000 cancers diagnosed in 1984 and entered in the National Registry, 1500 were attributed to occupational exposures. However, only 52 men with cancer received compensation during that period. Caroyer gave a series of reasons for the cancer cases evading the system among which is that only a few types of cancer are recognized by the Belgian Foundation for Occupational Illnesses as being associated with occupational exposures, including mesothelioma and asbestos, upper respiratory tract cancers and wood dusts, and skin cancer.

Using atomic absorption spectroscopy, Raitchel et al. (Ref. 121) determined the concentrations of nickel and chromium in biopsied lung tissue taken from eight German metal workers who had lung cancer. Concentrations of nickel and chromium as high as 100 times greater than in control populations were observed in all of the samples. All of the metal workers had been occupationally exposed to nickel and chromium and all but one had smoked cigarettes. Four of the patients had been welders of stainless steel, and a fifth patient had been a flame- and plasma-cutter of stainless steel. Six of the eight patients, including all the welders, had been granted disability payments for their diseases. While the concentrations of nickel and chromium were elevated in the lungs of the welders, the authors stated that it cannot be concluded that these metals caused their cancers because an association between nickel and chromium in welding fumes and cancer has not been clearly established. They stated, however, that quantitative determination of nickel and chromium in biopsied lung tissue can provide data useful for determination of occupational exposure in individual cases and can facilitate decisions regarding liability.

Dufresne et al. (Ref. 42) used transmission electron microscopy and phase contrast microscopy to examine lung tissue from four aluminum smelter workers who had died from lung cancer and one who had died from

mesothelioma. The last subject had been exposed to amosite asbestos during summer employment for 2 years, and fibers of that material were found in his lung tissue but not in tissue from the four who had died from lung cancer. Plaques or fibrosis were present in all of the lung cancer cases, one of whom was a welder who had died of squamous cell carcinoma. Mild fibrosis was found adjacent to the tumor in the lung tissue from the welder. All of the lung cancer cases had been smokers, and all had been exposed to some level of polycyclic aromatic hydrocarbons during their work experience. Asbestos fibers, fragments of silicates, and metal-rich non-fibrous particles of chromium, cobalt, and aluminum were detected. The authors noted that their results may not be representative and that the wide range of particle types identified in the lungs illustrates the difficulty of ascribing causality of disease among workers in a complex environment such as that of an aluminum smelter.

9.2 Cancer of the Trachea. Carcinoma of the trachea, is a rare form of cancer that occurs twice as frequently in men as in women. Theegarten et al. (Ref. 146) described the case of a 58-year-old man who had died from this disease. He had worked as a plumber and fitter for over 41 years and, during his career, had been exposed to asbestos, man-made mineral fibers, and welding fumes. He had also been a heavy smoker. Histologic examination of autopsied lung tissue revealed iron-containing particles and fibrosis in areas surrounding the bronchioles. Energy-dispersive X-ray analysis revealed aluminum, iron, magnesium, titanium, chromium, vanadium, and silicon (Al, Fe, Mg, Ti, Cr, Va, and Si) in the dust deposits. Asbestos, man-made mineral fibers, and what were considered to be “deposits of welding fumes” because of their Cr, Ti, and Va content, were also identified. Theegarten et al. concluded that a relationship between the tracheal carcinoma and the mixed pneumoconiosis seems probable.

9.3 Cancers Associated with Electromagnetic Fields (EMFs). Theriault (Ref. 147) reviewed and evaluated the literature concerned with human health risks from EMFs. Several studies published before 1992 showed increased risk for leukemia and brain cancer among groups of workers exposed to EMFs, but there were also studies which found no effects and, in most of the studies in which welders were identified, there were no EMF-related effects among welders. More recent investigations of EMF-related cancer have shown increased risks for leukemia among electrical workers, but welders were not included in the populations studied.

9.4 Cancer of the Central Nervous System. Wilkins and Wellage (Ref. 166) analyzed data from a previously-published case-referent study which had used cases identified through the Columbus, Ohio, Children’s Hospital Tumor Registry (Ref. 165). Information concerning pa-

ternal occupation was available for 94 cases (patients younger than 20 years old who had CNS tumors) and 166 referents. Occupations with presumed exposure to EMFs included several types of electrical workers, welders, and other workers who used electrical machinery. Cases were matched with referents according to paternal exposure prior to conception or during pregnancy. Preconception exposure to occupational EMF was found to be only weakly associated with increased risk for CNS tumors in offspring, while a stronger, but still not statistically significant, association was seen for paternal welding. The authors noted that the results could have been affected by several possible weaknesses and biases. In the case of welders, there are confounding exposures to chemicals and to environmental stresses such as heat.

9.5 Cancer of the Eye. Uveal melanomas occur on the inner lining of the eye and are the most common type of tumor to occur in the eye. This tumor rarely occurs in dark-skinned or dark-eyed individuals. Holly et al. (Ref. 69) conducted a case-control study in the western United States of the relationship between the development of uveal melanoma and occupational or leisure-time exposures. The cases were all white males, residents of eleven western states, diagnosed with, or treated for, uveal melanoma or melanoma of the iris at the University of California, San Francisco, between January 1978 and February 1987. Controls were chosen by random digit dial telephone methods. Two controls were matched to each case by age group and geographical area. Men who had been exposed to welding for at least 3 hours per week for 6 months or longer were included in the welders group. Total asbestos exposure was estimated from job and industry descriptions provided by the subjects. Substantially elevated relative risks for ocular melanoma, in descending order of risk, were found for chemists, chemical engineers, or chemical technicians; sailors, ship officers, or fishermen; welders and those in close proximity to welding operations; and health-related occupations. The calculated odds ratios were adjusted to account for eye color and tanning or burning response to a 30-minute exposure to strong sunlight. Patients with uveal melanoma were significantly more likely to have been exposed to asbestos, and the risk of developing the disease increased significantly with increased exposure. For welders, the increased risk of ocular melanoma was significant (adjusted OR = 2.2, CI = 1.3–3.5), but there was no apparent increase in this cancer with increasing years of exposure. In a previous study, Holly et al. had found that a single severe burn to the eye (such as may occur during welding) was associated with increased risk for uveal melanoma, so they concluded that the present study may have underestimated the number of cases associated with welding by excluding those whose intensity or duration of welding did not meet their

requirements for inclusion as “ever welding.” The authors interpreted their results as indicating that intense ultraviolet (UV) light exposure to the eye is associated with an increased risk of uveal melanoma.

9.6 Prostate Cancer. A case-referent study of 345 prostate cancer cases and 1346 referents was carried out in the Netherlands by van der Gulden et al. (Ref. 154) to investigate the relationship between work environment and prostate cancer risk. Cases were selected from a regional cancer registry. Referents were men diagnosed with benign prostate hyperplasia who were recruited with assistance of pathology laboratories in the same region. Questionnaires were mailed to all subjects to obtain information on their work history and occupational exposure. The incidence of prostate cancer was nonsignificantly increased among those who had held the job of welder the longest (OR = 1.51, CI = 0.48–4.78) and among those who had worked as a welder between 1960 and 1970 (OR = 1.66, CI = 0.52–5.31). Farm workers (OR = 7.82, CI = 2.09–29.29) were found to have significantly increased odds ratios for the disease. Exposure to cadmium was associated with a statistically significant increased risk of prostate cancer (OR = 2.76, CI = 1.05–7.27). A nonsignificantly increased risk for prostate cancer was found among those exposed to welding fumes (OR = 1.19, CI = 0.73–1.95) and to other industrial hazards including pesticides, fertilizers, iron and steel, non-ferrous metals, cutting oils, leather products, and ionizing radiation.

9.7 Malignant Lymphoma. Figgs et al. (Ref. 49) used death certificate data to examine the relationship between non-Hodgkin’s lymphoma and occupation. The 23,890 cases and 119,450 non-cancer controls were from 24 states in the U.S. Only a few occupations were found to be positively associated with the disease. The authors suggested that significantly increased risks observed among teachers and white-collar workers may have been linked, in part, to socioeconomic factors, while the significant excess risk among some occupations involved with engine operation and repair may have reflected exposure to metals and solvents. An increased but statistically nonsignificant risk for non-Hodgkin’s lymphoma was found among welders (6 cases, OR = 2.1, CI = 0.8–5.8). These results are supported by the conclusions of Persson (Ref. 115) who recently reviewed the literature linking occupational exposure and the incidence of malignant lymphoma (Hodgkin’s disease and non-Hodgkin’s lymphoma) and found little support for an association of these diseases with welding.

9.8 Biliary Tract Cancer. Chow et al. (Ref. 34) analyzed the association between occupational exposures and the development of biliary cancer in Shanghai, China, using standardized incidence ratios. Female service workers

were the only broad category of workers that displayed a significantly elevated risk for the disease. In more narrowly defined occupational categories, female public service workers, textile workers, and transportation equipment operators had a statistically increased risk for biliary tract cancer. A nonsignificant excess risk was found for both male (SIR = 1.53, CI = 0.61–3.15) and female (SIR = 1.40, CI = 0.45–3.27) workers in the category of plumbers, welders, and sheet metal workers.

10. Magnetopneumography and Related Techniques

Magnetopneumography (MPG) is a noninvasive technique which can be used to measure the amount of magnetizable particles that have been inhaled and retained in the lung. Using this technique, numerous studies have measured the retained ferric oxide particles in the lungs of welders. Some early studies had demonstrated a positive relationship between the content of ferromagnetic particles in the lung and the profusion of small rounded opacities, indicative of siderosis, in chest X-rays (Ref. 54).

In 1995, Hogstedt et al. (Ref. 68) re-examined the relationship between the lung particle burden determined by chest X-rays and by MPG. First, they validated the precision of the MPG instrument using a welding fume sample with a measured quantity (35% by mass) of magnetite (Fe_3O_4). Cylinders containing different quantities of the welding fume sample were subjected to MPG. The correlation between the known quantity of magnetite added to the test cylinders and that determined by MPG was very high ($r = 0.9978$, $P < 0.05$), indicating that the MPG instrument yielded precise and accurate data.

Using MPG, the relation between the mass of magnetizable particles retained in the lung and the duration of the welding experience was studied in 112 shipyard welders who had exclusively used SMAW to weld black steel. Data concerning occupational experience were obtained by interview. A weak, but statistically significant, correlation ($r = 0.45$, $P < 0.05$) between the lung burden of magnetizable material and the time spent in the welding profession was found. The wide variability between subjects was attributed to factors such as inter-individual physiological differences and to variations in the ventilation and fume concentrations in their workplaces.

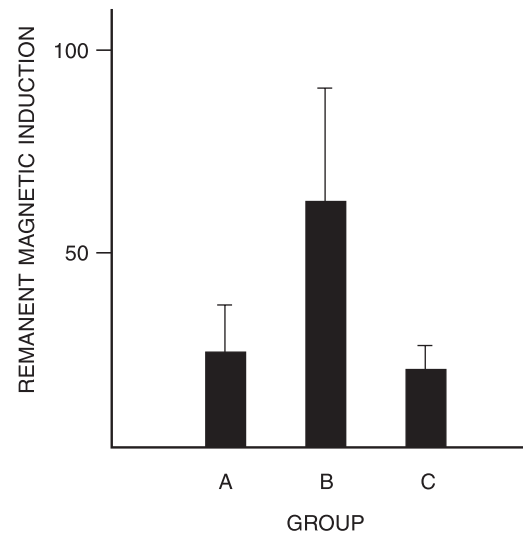
The quantities of magnetite in the lungs, as measured by MPG and by analyses of chest x-rays, were compared in 23 of the welders. Two radiologists analyzed the chest X-rays and ranked them according to visual estimates of the amount of retained particulate in the lungs of each subject. The correlation between the amount of iron retained in the lungs, as determined by MPG and the rankings

obtained by the visual analyses of the chest X-rays, was weak and was not statistically significant.

Hogsted et al. speculated that differences between their results and those of other investigators who had demonstrated a more positive correlation between chest X-rays and MPG measurements may have been related to differences in welding exposures and to the range of ages of the study participants. They concluded that MPG is highly sensitive to retained magnetizable material in the lung and that analysis of chest X-rays provides far less reliable estimates of the particulate lung burden. They noted that further studies should compare MPG data with that obtained using more sophisticated roentgenological methods, such as high resolution computed tomography (HRCT).

Kruty et al. (Refs. 85 and 87) compared the particulate lung burdens in two groups of active arc welders in the Slovak Republic. Measurements were made with Superconducting Quantum Interference Detectors (SQUID). The first group comprised eight men who welded both ferrous and nonferrous metals for more than 10 years (Group A). The second group comprised eight welders who had been employed continuously in one shipyard for more than 10 years and had worked primarily in enclosed areas where the concentration of welding fumes was high (Group B). The eight controls were nonsmokers of a similar age range to the welders, who had had no known occupational exposure to magnetizable particles. Chest X-rays showed no signs of fibrosis, and pulmonary function was normal in all participants. Significantly greater quantities of magnetizable substances were found in the lungs of the welders who had worked in confined spaces (Group B) than in welders who had had better working conditions (Group A) and than in controls (see Figure 4). Only small, nonsignificant differences were detected between Group A welders and controls.

The relationship between the duration of the welding experience and the quantity of magnetizable substances retained in the lungs was examined in nine welders who had worked for 9 to 37 years under conditions similar to those of Group B welders (Ref. 86). The content of magnetizable particles in the lungs was roughly proportional to the duration of the welding experience. The highest concentrations were seen in two subjects who had welded for 37 and 31 years. The lowest quantities of magnetizable material were seen in the lungs of the two men who had welded for the shortest period of time (9 years for both). Varying quantities were detected in the lungs of the remaining five welders whose welding experience ranged from 14 to 36 years. The authors concluded that the magnetizable substances were particularly evident in welders who worked in small confined spaces. They stated that methods such as HRCT,



General Note: Average changes in the remanent magnetic field (with 95% confidence intervals) for eight men who welded both ferrous and nonferrous metals for more than 10 years (Group A), for eight welders who had worked primarily in enclosed areas where the concentration of welding fumes was high (Group B), and for controls (Group C). Data from Kruty et al., Ref. 86.

Figure 4—Comparison of Retained Iron in the Lungs of Welders and Controls

nuclear magnetic resonance, and bronchial lavage should be used to verify MPG studies.

Sosnitzky et al. (Ref. 136) noted that previous MPG studies had indicated that up to 50% of inhaled iron particles are cleared from welders' lungs within a year after exposure, but the fate of the cleared particles is not entirely understood. A possibility considered by Sosnitzky et al. is that some of the iron is carried from the lungs via the blood stream and deposited in vital organs, potentially causing iron overload syndrome. Chronic iron overload or hemochromatosis is a common inherited disorder in which excessive amounts of iron are absorbed through the gut from the diet and deposited in various body organs, primarily the liver, but also the heart, pancreas and other organs. Early indications of the disorder are elevated serum iron, elevated transferrin-bound iron (transferrin saturation), and elevated serum ferritin levels. Since it takes many years for sufficient iron to build up in the organs, disease processes resulting from this disorder do not usually occur until 30 to 40 years of age. The effects of this condition can be quite severe and typical manifestations are cirrhosis of the liver, diabetes, enlarged heart, cardiac arrhythmias, and heart failure.

While hemochromatosis is most frequently caused by inherited factors, acquired forms of the disease from ex-

cessive exposure to iron may also be possible. To investigate this possibility in welders, Sosnitzky et al. (Refs. 136 and 89) used noninvasive biomagnetic methods [magnetocardiography, magnetic-susceptibility plethysmography (MSPG), and low temperature electron spin resonance spectroscopy] to examine male welders in Ukraine with pneumoconiosis or chronic bronchitis. Excess iron in the body, or iron overload, was diagnosed by measurements of serum iron and serum iron-binding capacity. Serum iron concentrations were elevated more frequently in welders with pneumoconiosis than in those with chronic bronchitis. In some welders, magnetocardiography measurements yielded data suggestive of deposition of iron in the heart muscle and heart enlargement. These changes correlated with MSPG changes suggestive of iron overloading in the liver and with pneumoconiosis. The authors concluded that, in patients with pneumoconiosis, iron may leave the lungs through the blood stream and may become deposited in the heart and liver. They suggested that this could have physiological manifestations such as the promotion of lipid peroxidation which has been studied extensively by Gelelskul and his colleagues in Ukraine (Refs. 55 and 56).

11. Effects on the Ear

Mahmoud et al. (Ref. 96) measured noise levels and tested hearing thresholds (minimum detectable sounds levels) among workers at a pipe factory in Libya. The production process, performed in a single large room, consisted of unrolling and cutting steel plates, re-rolling, and linear welding. Continuous noise levels from these processes were between 96 and 98 decibels (dB). Impulse noise levels of about 106 dB were generated six times per minute by collision between the pipes as they came off the production line. At a work site where pipes were galvanized, impulse noises of 106–112 dB were generated three times per minute by an air-jet cleaner. A total of 71 workers who had been employed at the factory for at least 5 years were examined for hearing loss. Occupational noise-induced hearing loss (OIHL) usually first appears as a deficit at a frequency of 4000 hertz (Hz), which was seen in 37 (52%) of the examined workers. The authors used a British standard which defined OIHL as a greater than 30 dB hearing loss at frequencies of 1000, 2000, and 3000 Hz. By this criterion, 14 (20%) of the workers were determined to have OIHL. Age and years of exposure were significant determinants in the development of hearing loss at 2000–4000 Hz, but these two parameters were not independent of each other.

Short-term effects on hearing in a group of Ukrainian workers engaged in rolling, press forging, and welding of electrical conduit were studied by Mukhin (Ref. 101).

Hearing thresholds were determined in all of the workers throughout a workshift. Average hearing thresholds rapidly increased during the workshift, and the changes were statistically significant at 1000 and 2000 Hz. Long-time welders, with an average experience of 16 years, had a greater hearing deficit at 4000 Hz than did those with an average length of service of 4 years. The hearing threshold was only slightly increased in an unexposed control group of engineers and factory administrators.

Ivanovich et al. (Ref. 75) measured workplace noise and tested hearing sensitivity in 229 workers in a Bulgarian sheet metal factory. The workers had an average age of 36 years and had worked in the factory for an average of 10 years. Excessive continuous and impulse noises were detected in the workplace. Hearing thresholds were measured at 4000 and 6000 Hz and at average speaking frequencies. The proportion of subjects with hearing thresholds above 30 dB for all frequencies tested was greater among roller workers, furnace men, cutters, and crane workers than among fitters, welders, and electricians who were exposed to lower noise levels or were exposed for shorter times to intense noise. Statistical analysis showed that the deficits in hearing sensitivity were more closely related to age than to the duration of occupational experience.

Bruhl et al. (Ref. 25) measured noise levels in a Swedish automobile plant on four occasions between 1967 and 1991. Welding was performed in two of the buildings that were monitored, the southern assembly shop and the northern pressing and assembly shop. Noise levels greater than 85 dB declined substantially during the 25 years in which they were monitored, as is shown in Table 9. Both noise reduction measures and improved quality control, which eliminated extra processes such as grinding of pressed parts, contributed to the reduced noise levels in the plant.

12. Effects on the Eye and Vision

Zlateva (Ref.170) examined the incidence of eye diseases in two groups of Bulgarian welders. The first group consisted of 190 persons who had come to the clinic with visual complaints. All of these welders had experienced repeated episodes of photokeratitis (arc eye). The average total number of episodes experienced per person was six for welders with less than 10 years work experience and twelve for welders with more than 10 years experience. Among the latter, 12% suffered from chronic photophthalmia (increased sensitivity to light) and 9% from chronic conjunctivitis.

The second group consisted of 116 clinically healthy electric arc welders who were examined at their place of work. The proportion of welders with lens changes and

Table 9
Decrease in Noise Levels in Two Areas of a Swedish Automobile Plant

		Percent of Plant Area With Noise Levels in Different Ranges			
		Noise Level in Decibels (dB)			
Plant Area	Year	>105	95–104	85–94	<85
Southern Assembly Plant	1967	0.00	16	68	16
	1991	0.00	0.00	4	96
Northern Pressing and Assembly Plant	1967	5	63	27	5
	1991	0.00	6	11	83

General Note: Adapted from Bruhl et al., Ref. 25.

cataracts was compared with that of a control group of 100 workers who had no occupational exposures to radiation. The incidence of lens changes and cataracts was significantly higher for welders under age 45 than for controls in the same age range.

Damage to the retina of the eye may result from exposure to blue visible light or from thermal injury following exposure to infrared radiation (Ref. 157). Welding-related retinal lesions (arc welder's retinopathy) 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. A case of arc welding maculopathy was described by Arend et al. (Ref. 10). The patient, a 26-year-old male welding student, experienced blurred vision in both eyes immediately after leaving a 4-hour arc welding course. He had been improperly instructed about choice of protective lenses and chose to use lenses that afforded him the greatest visibility of the weld area without being adequately protective against visible light radiation. Examination 12 hours later, revealed oval white lesions in the foveas of both eyes with a blind spot in each eye and small loss of visual acuity. Little improvement was seen upon examination 1 year later. The investigators concluded that the injury was probably due to excessive exposure to blue and blue-green light or to light of a longer wavelength.

Using data collected from five Danish hospitals, Holmich et al. (Ref. 70) investigated the incidence and cause of eye injuries that occurred during avocational activities between 1989–1991. A total of 9900 accidents were identified which involved the eye. Of these, 2940 occurred during activities associated with hobbies, 1460 of which occurred while using drilling, welding, or grinding equipment. The majority of these accidents involved men engaged in automobile repair. The incidence

of eye injuries occurring during these activities increased by 30% between 1989 and 1991. Foreign-body lesions and actinic conjunctivitis were seen in 60% and 30% of the cases, respectively. Most of the eye injuries were painful but not serious. The authors concluded that the use of proper eye protection would have prevented all the injuries.

13. Effects on the Skin

13.1 Dermatitis. Ultraviolet radiation of the skin from the welding arc frequently causes mild erythema (sunburn-like reddening of the skin) with no further consequences. Some pre-existing or allergic skin conditions such as atopic dermatitis, an allergic condition which produces eczema, may render individuals uniquely sensitive to UV light. Atopic dermatitis is exacerbated by infrared and UVB radiation in about 10% of the patients with this condition.

Elsner (Ref. 44) described the case of a 32-year-old welder with atopic dermatitis that was exacerbated by exposure to UVC radiation, which is the major form of UV radiation emanating from the welding arc. The welder had a personal history of childhood asthma, allergic rhinoconjunctivitis, and scaly eczema (atopic dermatitis) which was aggravated by exposure to sunlight. He started welding at the age of 25 and soon thereafter experienced skin lesions in the face and neck area. Although a welding shield that covered his face and neck prevented most of the reaction, it could not be used while spot welding, doing delicate work, or welding in limited space. The lesions regressed when he was off work and treatment with topical and systemic steroids helped to control the condition. He ceased welding after a year because of recurrent eczema and his skin condition improved considerably.

He returned to welding 5 years later which resulted in serious exacerbation of his skin problems. Treatments that were previously effective no longer helped and he had to be hospitalized. After this, the patient left welding work permanently. Skin prick tests indicated that the patient was sensitized to a wide range of common allergens. Further tests showed that he was highly sensitive to UVC radiation but not to UVA or UVB. The authors concluded that UVC radiation emanating from the welding arc had been responsible for causing his skin lesions. Infrared radiation could not be ruled out as a contributing cause.

Oiso (Ref. 104) described the case of a 44-year-old Japanese man with 30 years welding experience who developed severe dermatosis on his right hand. The welder first noted a pigmented patch on his hand after welding for about 10 years. A red, inflamed area with erosion and crust appeared within this area about 20 years later. Histopathological examination of a biopsied section of the skin showed the presence of Bowen's disease, a precancerous, slow growing skin disease that may become malignant. Oiso attributed the development of this condition to exposure to UV or infrared radiation from the welding arc.

13.2 Burns. Injuries from fires, explosions, and related incidents reported to the United Kingdom Health and Safety Executive between April 1992 and March 1993 were summarized and reviewed by Owens and Hazeldean (Ref. 108). A total of 675 injuries, including 21 fatalities, were reported. Twenty incidents involved gas welding equipment and resulted from leaking or burst acetylene, fuel gas, or oxygen hoses. The use of cutting and welding equipment was responsible for the burns experienced in an additional 24 incidents. The authors stated that the injuries sustained by the welders could have been prevented by use of suitable gear such as hand and arm protectors.

Serious burns have been reported to occur from sparks produced during resistance welding. When the current is too high in resistance welding processes (e.g., spot, seam, projection, or butt welding), free molten metal forms which can be ejected from the weld site as metal sparks. The sparks increase in size and number as the current is increased. Because of the high pressure associated with resistance welding, the sparks are often ejected at high velocities. These sparks can penetrate deeply into the skin and may require surgical excision. This is not an uncommon problem. Four such injuries were described in 1993 (Ref. 2) and 1994 (Ref. 57). More recently, Shanahan described (Ref. 129) five additional cases which occurred within a one-month period at a motor vehicle factory. Three of the cases were injuries to the hand which occurred while leather gloves were worn. The fourth injury involved the penis. In that case, a leather apron was not worn, ostensibly because it was too hot.

The fifth case involved injury to the left forearm of a welder who was not wearing a gauntlet. Surgical excision of the metal particles was required for each of these injuries and, in all but the last case, skin grafting was necessary. The authors explained that, in such wounds, the heat transferred into the surrounding tissue from the molten metal frequently causes necrosis which must be removed to avoid infection. X-rays of the wound are necessary before treatment to distinguish between a simple spark burn and a deeply penetrating foreign body.

14. Effects on the Nervous System

14.1 Amyotrophic Lateral Sclerosis. Amyotrophic lateral sclerosis (ALS or Lou Gehrig's disease) is a fatal, progressive, degenerative condition of the nervous system. This uncommon motor neuron disease is usually fatal within 2 to 3 years of onset. The incidence of ALS has increased substantially during the last several decades. Although its cause is not established, it is frequently attributed to environmental exposures.

Vanacore et al. (Ref. 152) described the case of a 44-year-old welder with ALS. After being employed for 13 years as a welder, working mostly with SMAW or GMAW in confined spaces with inadequate ventilation, he began to experience muscle twitches and weakness in the limbs. His condition was diagnosed as ALS. The authors speculated that exposure to lead may have contributed to his disease, but analyses conducted at the time of diagnosis showed that his urine and blood lead concentrations were within the upper limits of normal. In addition to exposures to welding fumes, he had routinely used solvents such as white gasoline, toluene, dichloropropane and had frequently welded painted surfaces. The authors concluded that the etiology of the disease in this patient was consistent with the hypothesis that ALS may result from exposure to solvents and metal fumes.

Strickland et al. (Ref. 140) conducted a case-control study in which 25 ALS patients who were being treated at the University of Minnesota ALS Clinic were compared with two groups of age- and sex-matched controls residing in the same geographical area. The first control group consisted of patients from the University's Muscle Disease Clinic with non-ALS neuromuscular diseases. The second control group consisted of randomly selected residents from the local community. The average age of subjects and controls was 56 years and the gender ratio in each group was 52% male. Occupational histories and exposures were ascertained by questionnaire and personal interviews. Patients were asked if they had worked in any of 27 industries or had ever experienced any of a number of occupational exposures. Welding was listed separately among the industries but was grouped with

soldering materials in the list of exposures. The strongest association with ALS was exposure to welding or soldering materials (OR = 5.0, CI = 1.4–20.1) and working in the welding industry (OR = 5.3, CI = 0.97–26.0). With electric plating, there was a high odds ratio (OR = 8.0, CI = 0.9–72] but low statistical significance ($p < 0.07$). The authors speculated that lead might be the common toxicant present in welding and soldering that was responsible for the disease. However, many welders never work with lead, and the aerosols created by soldering can be vastly different from those generated by welding. The authors recognized that it is difficult to reach strong conclusions from a case-control study of this nature with such a small sampling size.

14.2 Manganese and Aluminum. Effects of manganese and aluminum on the nervous system were examined in welders by Sjogren et al. (Ref. 132). A comprehensive battery of psychological and neurophysiological tests were administered to groups of welders with a history of exposure to either of the metals. The aluminum-exposed cohort comprised 38 welders with an average 17.1 years welding experience, at least 5 years exposure to welding fumes containing aluminum, and less than 10 hours experience welding lead or high alloy manganese steel. Twelve railway track welders who had an average 19.5 years welding experience, a total of more than 100 hours welding high alloy manganese steel, and less than 25 hours exposure to lead or aluminum welding fumes, served as the manganese-exposed group. Controls were 39 railway track welders whose main exposure was to iron. They had an average of 13.8 years welding experience and had less than 25 hours experience welding high alloy manganese steel, lead, or aluminum. Manganese levels in blood did not differ among groups of welders but urinary aluminum concentrations were about seven times higher in the aluminum welders than in controls.

The welders exposed to aluminum reported experiencing more fatigue and had significantly lower scores in five of the motor function tests than did the controls. The results were dose-related for two of these tests which adds support to the association between the observed effects and the aluminum exposure. The twelve welders exposed to manganese also had significantly lower scores in five of the motor function tests and reported a higher degree of sleep disturbances than did controls. In addition, the manganese-exposed welders showed deficits in one of the neuropsychological tests. The authors concluded that neurotoxic effects had resulted from manganese and aluminum exposures in the study participants. They noted that subtle differences in motor function have been observed in aluminum-exposed workers with urinary aluminum concentrations of about 50 $\mu\text{g}/\text{L}$ and recommended that measures should be taken to reduce aluminum exposures among welders.

15. Effects on the Musculoskeletal System

15.1 Carpal Tunnel Syndrome. Carpal tunnel syndrome is brought about by compression of the nerves leading to the hand due to chronic inflammation of the tendon sheaths in the wrist. It is characterized by pain, tingling, and numbness in the hand, often exacerbated at night, and can result from repetitive wrist movement tasks or from use of vibrating hand-held tools. Phalen's test for the syndrome is deemed positive if numbness and/or tingling develops in the fingers within one minute of maximum extension of the wrist (Ref. 4).

Baldasseroni et al. (Ref. 11) conducted a case-control study of the prevalence of carpal tunnel syndrome among workers with different job classifications. The study population consisted of 833 patients with carpal tunnel syndrome (103 males and 730 females; mean age 48) who were selected from the computerized medical records of a large regional hospital in Italy. The 3222 controls (1765 males and 1457 females; mean age 43.5) were hospitalized for other reasons. The excess of females among the study subjects reflects the generally higher incidence of this syndrome in women than in men. The study subjects were classified according to job categories defined by the Italian National Institute of Statistics. A statistically significant risk for carpal tunnel syndrome was found in the following job classes: spinners, weavers, and dyers; knitters, tailors, hat makers, and upholsterers; tanners, shoemakers, and leather manufacture workers; and hotel and restaurant cooks. The incidence of carpal tunnel syndrome was nonsignificantly elevated in the job classification carpenters and welders (OR = 2.4, CI = 0.54–10.62).

Andersson et al. (Ref. 4) described the case of a 31-year-old right-handed man who had been employed in automobile manufacturing for 13 years. Three weeks after switching to a job that required positioning a spot welder beneath cars moving overhead, he complained of pain in both wrists and numbness in the fingers of his left hand. Phalen's test for carpal tunnel syndrome was positive for the left hand. Wrist splints, prescribed by the examining physician, which were worn only at night, relieved the numbness for a time. After six months, the patient complained of further weakness, pain, and numbness, and carpal tunnel syndrome was confirmed bilaterally. The patient had surgery on both hands and was placed in a nonwelding position on the assembly line. In one such job, the use of a stapling gun brought about a return of intense symptoms within three weeks. The symptoms subsided, but were not completely eliminated, when the worker was given a position driving a forklift truck. Nighttime splints were still required to allow the patient to sleep through the night.

15.2 Epicondylitis. Ritz (Ref. 123) examined 290 male employees of a water works in Hamburg, Germany for

evidence of humeral epicondylitis (commonly known as “tennis elbow”), an inflammation caused by repeated strain to the tendons at the elbow. The workers were grouped according to their potential for experiencing biomechanical strain to the elbow based on their work histories. Welders and pipe fitters made up the highest exposure group, because of the forceful rotation of the elbow joint that is required while they are holding and fitting heavy pipes. This category included 77 men, 31 of whom had been transferred to less demanding jobs. The group with moderate exposure consisted of 52 current and 79 former mechanics, plumbers, electricians, and construction and maintenance workers. The unexposed category consisted of 82 office workers, engineers, and supervisors whose jobs involved no elbow strain.

Diagnosis by the response to three pain provocation tests (pain during palpation of the elbow, pain during resisted movements of the wrist and fingers with an extended elbow, and elbow pain while lifting a chair) revealed 41 cases of epicondylitis. Signs of this condition were observed in 20% of the workers in the highest exposure group, 14% of the workers in the moderate exposure group, and 10% of the unexposed workers. When the prevalence of epicondylitis was analyzed with respect to the duration of the work experience in each job category, significant differences emerged between the exposed and nonexposed workers. Comparison with the unexposed group showed that statistically significant increases in the incidence of humeral epicondylitis occurred after ten years of exposure among current workers in the moderately-exposed group and among both current and former welders and pipefitters in the highly exposed group. Having previously worked in a high exposure job for 24 years was associated with a 6.3-fold increase in the prevalence of epicondylitis. There was a positive dose-response relationship between epicondylitis and years of employment in welding and pipefitting, which strengthens the association between the disease and the occupational exposure. The authors concluded that the prevalence of epicondylitis increases with the duration of exposure and that the persistence of epicondylitis in former pipefitters and welders conflicts with the description of the disease in some medical texts as a self-limiting condition of short duration.

15.3 Lower Back Pain. Factors associated with occupationally-related lower back pain include heavy physical work, static work postures, frequent bending and twisting, repetitive work, frequent use of vibrating tools, and lifting, pushing, and pulling (Ref. 4). The most risky jobs are those that involve multiple risk factors such as rapid lifting of heavy objects combined with bending or twisting (Ref. 53). Individually tailored rehabilitation helps, but workers who face the same risk factors are susceptible to re-injury when they return to work (Ref. 161).

Wickstrom et al. (Ref. 164) described a video-based method for evaluation of the physical load on the lumbar spine in workers during normal work activity. A standard model developed by the University of Michigan (Ref. 151) was used to calculate loads on the lowest lumbar disc. Strain in the same area was classified according to observed extension and flexion (bending) of the fascia (fibrous connective tissue that surrounds muscles). The Michigan model took into account body posture and attitude of the back, the weight of the external burden and its distance from the body, and the amount of external support. For the purpose of the analyses, a load of 3000 newtons (N), equivalent to 674 pounds was taken as the upper limit for disc compression in industrial work. This load is associated with some risk of back injury, depending on the duration of exposure and the susceptibility of the individual. It is roughly half the load described as being definitely harmful by NIOSH (Ref. 102). An intermediate level of compression was chosen as 1500 N (337 pounds).

This video-based technique was demonstrated with nine workers, including three welders. For analysis of spinal loading, video recordings were made for periods of 5 to 15 minutes as the workers conducted their normal tasks. Using the videos, spinal loading and deformation of the fascia could be determined by analyzing the workers’ postures, the external loads, and the duration of each of these load combinations during the performance of each task. The loads were calculated using the Michigan formula. Compression of the lowest lumbar disc never exceeded the upper limit of 3000 N in any of the welding tasks. The jobs that caused the most prolonged disk compression in excess of 1500 N and continuous lumbodorsal fascia strain were grinding of the weld bead and carbon-arc gouging. However, according to the welders’ estimates, these tasks were performed only about 1% of the time. Horizontal and vertical fillet welding consumed more than 60% of the welders’ time. Performance of these tasks also caused a moderate level of disc compression, but the compression was not continuous and occurred about 15–20% of the time that it took to complete the task. The task which produced the greatest proportion of rotational strain was overhead welding, which consumed an average of 8.8% of the welder’s work day. The authors recommended the use of video-camera techniques in occupational health and safety practice to provide data on loads on workers’ musculoskeletal systems and for devising and evaluating methods to reduce the risk of injury.

16. Effects on the Kidney

16.1 Chromium. Proteins are a normal component of urine, but elevated levels (proteinuria) can be a symptom

of kidney disease. Excretion of low molecular weight proteins, such as beta-2-microglobulin and retinol-binding protein, is generally thought to result from damage to the kidney tubules while excretion of high molecular weight proteins, such as albumin, is characteristic of glomerular dysfunction. Chronic exposure to low concentrations of cadmium fumes can cause kidney damage, which is first manifested by urinary excretion of low molecular weight serum proteins. Although it has been hypothesized that chronic exposure to low levels of chromium (Ref. 160) could also cause kidney disease, such effects have not been confirmed (Ref. 159).

To determine whether there are signs of changes in kidney function in chromium-exposed welders, Bonde and Vittinghus (Ref. 23) compared the concentrations of five proteins in urine samples from 102 metal welders and 33 referents who had never welded. The welder population consisted of 35 gas tungsten arc welders of stainless steel, 46 mild steel welders, and 21 ex-welders. Serum creatinine levels, creatinine clearance rates and urinary concentrations of beta-2-microglobulin were the same in the three welding groups and controls. Levels of albumin, immunoglobulin-G (IgG) and transferrin were significantly higher in the urine from active mild steel and stainless steel welders than in that from controls. Orosomucoid (a protein/carbohydrate complex) was significantly elevated only in urine from mild steel welders. Only one protein, albumin, was significantly increased in ex-welders. For the most part, the elevations in protein levels were not very high and all were within the upper limits of normal ranges. Breathing zone concentrations of welding fume particulate had been determined for 45 of the welders during an earlier study (Ref. 22). There was no relationship between the level of exposure of mild steel welders to welding fumes and concentrations of urinary proteins, nor were there differences between the protein excretion patterns in mild and stainless steel welders. In addition, no relationship was found between the number of years of welding experience and urinary protein levels. The authors concluded that exposure to fumes from welding stainless as well as mild steel alters the excretion of urinary proteins, but the association between welding exposure and clinically significant renal disease is questionable.

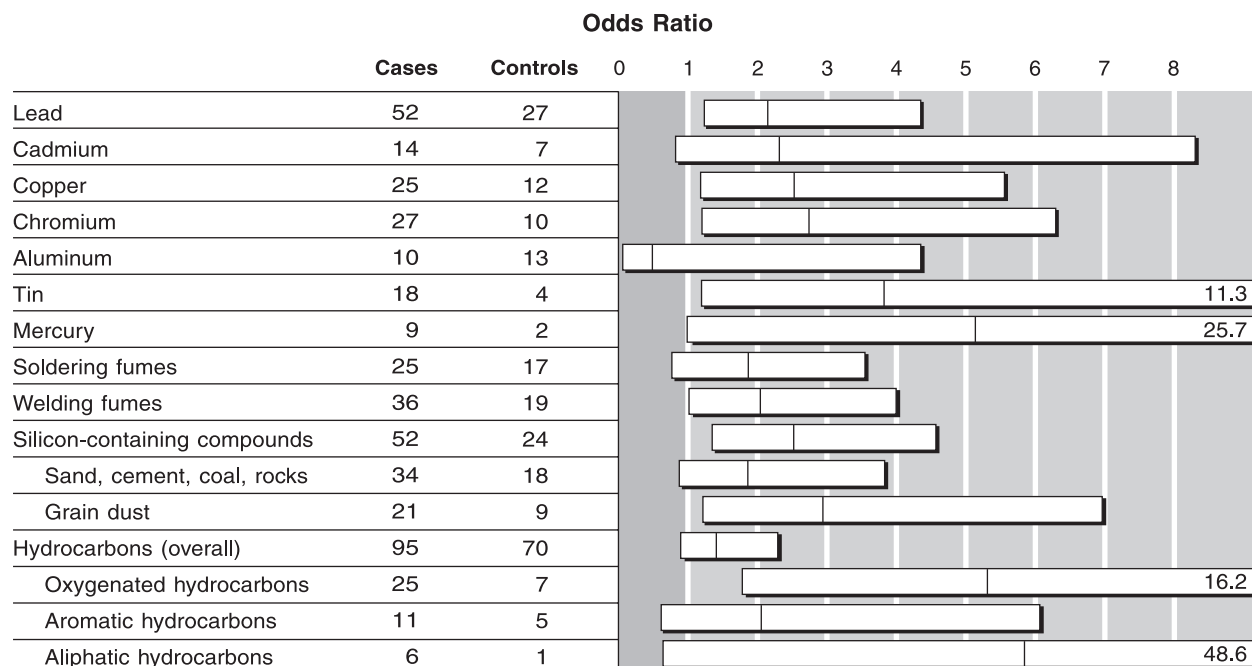
16.2 End-Stage Renal Failure. Chronic renal failure is a progressive, slow decline in kidney function. End-stage renal disease occurs when kidney function declines to such a low level that kidney dialysis or transplantation is necessary. The causes of most cases of chronic renal failure (CRF) are unknown. It is sometimes thought that there may be a link with occupational exposures, but the evidence for this is scarce. Even though cadmium is known to cause renal injury, an association between cadmium exposure and CRF has not been demonstrated.

Nuyts et al. (Ref. 103) conducted a case/control study to examine the role of occupational exposures in the development of CRF. The cases were 159 male and 113 female CRF patients recruited from renal units in three industrial areas in Belgium. Their mean age was 60 years. The 272 age- and sex-matched controls consisted of persons who were free of renal disease and resided in the same geographical areas as the cases. Occupational histories and exposures were obtained by personal interviews. Smoking habits were similar among the cases and controls, but the cases were more likely to have had a history of alcohol abuse and to have taken analgesics than were the controls. In addition, there were more blue collar workers among the cases than among controls. The risk for CRF was significantly increased by exposure to lead, copper, chromium, tin, mercury, and welding fumes, but not to cadmium (see Figure 5). Exposure to silicon-containing compounds, grain dust, and oxygenated hydrocarbons also showed an increased risk for CRF which, according to the authors, was a new finding. The duration of exposure to each of the pollutants was approximately 20 years. Cases with renal vascular disease had a higher-than-average exposure to welding fumes. Mean blood lead concentrations were significantly higher among the cases than the controls (8.7 versus 7.5 µg/dL). The authors concluded that the study confirmed previously identified risk factors for CRF, such as heavy metal exposures, and suggested that some additional exposures, such as grain dust, might also increase the risk.

17. Effects on the Cardiovascular System

17.1 Cardiovascular Disease. Hilt et al. (Refs. 65 and 66) investigated the prevalence of cardiovascular disease among workers at a Swedish stainless steel manufacturing plant. The 236 subjects were men who had worked at the plant for more than one year since 1960 and were under 70 years of age at the time of the study in 1993. Their average length of employment at the plant was 12 years. The study population included 46 workers with no history of exposure to aerosols produced by welding or grinding, 40 who had had only indirect exposures, and 150 who had worked with welding or grinding equipment. The 989 age-matched controls were randomly-selected men who lived in the town where the plant was located. None were metal workers and all had been employed for at least 5 years since 1960.

Data on the occurrence of cardiovascular and pulmonary symptoms and disease, occupational experience, and life-style factors were obtained by mailed, self-administered questionnaires. The data concerning cardiovascular disease



General Note: Data from Nuyts et al., Ref. 103.

Figure 5—Odds Ratios (and 95% Confidence Intervals) for Chronic Renal Failure Among Workers with Common Occupational Exposures

reported by 85 study subjects and 203 controls were verified by checking health information with their general practitioners. Historical information about the operations at the plant was gathered by industrial hygienists. In 1970, there were 170 production workers present in the plant. This was reduced to 50 by 1993. Grinders were separate from welders until about 1985; after that time, production workers did both grinding and welding. The proportion of welding methods used at the plant in 1993 was 60% GTAW, 10% GMAW, and 30% SMAW.

The proportion of men who reported having experienced chest pains on exertion and the proportion who reported having angina pectoris were significantly higher among the stainless steel workers than among the controls. The reported incidence of hypertension, myocardial infarction, and cardiac insufficiency or arrhythmias did not differ between the two groups. [The age- and smoking-adjusted prevalence of “chest pain on exercise” was 2.3-fold higher among the plant workers (CI = 1.5–4.9) than among the controls and that of angina pectoris was 2.6-fold higher (CI = 1.2–5.7).] A significantly greater proportion of men in the control group than in the study group considered their heart function to be “very good.” No significant differences were seen in the preva-

lence of chronic bronchitis and other respiratory symptoms between the two groups.

In a preliminary report of this study (Ref. 66), Hilt et al. concluded that the data indicated an increased risk of ischemic heart disease among welders. More detailed analyses of the study, published later as a full length report (Ref. 65), led to a somewhat different conclusion. When age, current smoking habits, education, and first degree relatives under the age of 50 with cardiovascular disease were taken into account, the incidence of chest pain on exertion, angina pectoris, and myocardial infarction were all higher in the plant workers than in the controls. However, statistical analysis showed that only grinders had a significantly increased risk for chest pain on exercise, angina pectoris and myocardial infarction (see Table 10). Only small, nonsignificant increases were seen in the welders. While there was a positive relationship between indicators of cardiovascular disease and years of employment at the plant, this was not the case for the relationship between indicators of cardiovascular disease and the estimated total amount of exposure. The investigators stated that this weakens their earlier conclusions concerning exposures at the plant and the occurrence of cardiovascular disease.

Table 10
Odds Ratios and 95% Confidence Intervals for Conditions
Consistent with Ischemic Heart Disease for Specific Exposures⁽¹⁾

	Odds Ratio (95% Confidence Interval)		
	Chest Pain on Exertion	Angina Pectoris	Myocardial Infarction
Any welding	1.8 (0.7–4.3)	1.4 (0.5–4.2)	1.8 (0.7–4.4)
Stainless steel welding	1.8 (0.7–4.6)	1.6 (0.5–5.0)	1.8 (0.7–4.7)
Grinding	2.4 (1.0–5.5)	3.3 (1.3–8.5)	2.5 (1.1–5.9)

General Note: From Hilt, Ref. 65.

Note:

(1) Age, amount of current smoking, length of education, and first degree relatives with cardiovascular disease under the age of 50 were included in analyses as potential confounding factors.

Sjogren (Ref. 134) reviewed the literature on the association between ischemic heart disease and occupational exposures to welding fumes and dusts of asbestos, beryllium, lead, and quartz. He cited two papers which suggested an increased risk of heart disease in welders, one of which was the first report of Hilt et al. discussed above (Ref. 66). Sjogren applied a hypothesis developed by Seaton et al. (Ref. 128) to explain the possible association between particulate air pollution in the workplace and possible increases in the number of deaths from cardiovascular and respiratory disease. Seaton's hypothesis was based on the release of mediators from leukocytes (white blood cells) responding to the deposition in the lungs of ultra-fine particulate pollutants from urban air. Macrophages and neutrophils activated by phagocytosis of particles release mediators that stimulate, among other things, the production of fibrinogen, a serum protein involved in blood clotting. Seaton postulated that the resultant increased coagulability of the blood could be responsible for the observed increases in cardiovascular deaths associated with urban pollution episodes. The synthesis of fibrinogen by the liver is stimulated by the cytokine interleukin-6 (IL-6) which is released from macrophages at the site of inflammation. Sjogren (Ref. 134) pointed out that Blanc et al. (Ref. 19) showed that IL-6 concentrations are increased in bronchoalveolar lavage fluid (BALF) from welders exposed to zinc-containing welding fumes which might induce the liver to produce more fibrinogen. Hilt et al. are currently conducting a study to test this hypothesis in which they are examining the content of IL-6 and fibrinogen in blood samples from welders during a full work week.

17.2 Vibration-Induced White Finger. Long-term use of handheld vibrating tools, such as pneumatic grinding

and chipping tools, can cause Raynaud's phenomenon or vibration-induced white fingers (VWF). This vascular syndrome is progressive with continued use of these tools. Whether or not this condition improves following cessation or reduction of exposure has not been established. To address this issue, Ostman et al. (Ref. 107) conducted a follow-up study of 59 welders with VWF who had worked at a Swedish shipyard company for 5 to 28 years (mean = 18 years) until it closed in 1988. These welders had been part of a cohort of 475 welders examined by these investigators in 1987. Of that cohort, 122 (26%) had symptoms of VWF, 18 of whom were subjected to the cold provocation test which provides an objective measure of the severity of VWF.

The follow-up study, conducted in 1993 and 1994, included 43 welders who had had little or no vibration exposure after the plant closed. Interviews of those welders revealed that 28 experienced improvement, eleven reported no change, and four felt that their condition had worsened since they ceased welding. Twelve of the men who had stopped welding when the plant closed were given the cold provocation test in 1987 and again during the follow-up study. The test indicated that the condition in one welder was unchanged, six welders showed some improvement, and five were markedly improved.

The remaining 16 welders who participated in the follow-up study continued working with handheld vibration tools after the plant closed. When examined in the follow-up study, either their conditions had not changed or they had worsened. The investigators concluded that VWF does not continue to progress following cessation of exposure to handheld vibrating tools and, in many cases, the condition may be reversible.

18. Effects on Reproduction

18.1 Effects on Fertility. Wu and Zhang (Ref. 168) studied the effects of exposure to manganese and welding fumes on semen quality. Specimens were provided by 63 men who had worked for at least one year in manganese mining and refining, 110 shipyard welders, and 38 machine shop welders. The 99 controls resided in the same regions as the study subjects and had similar socioeconomic backgrounds but had no occupational exposure to manganese or to compounds believed to interfere with reproductive processes. The average workplace air concentrations of manganese at the time of the study were 0.14 mg/m³ for manganese mining, 5.5 mg/m³ for manganese refining operations, and 0.25 mg/m³ for machine shop welding. Average welding fume concentrations ranged from 6.5 to 82.3 mg/m³ for different welding stations. Airborne concentrations of Mn, Fe, Cr and Ni were higher than allowable standards in a number of air samples collected in the work areas of the welders. Concentrations of Mn, Cu, Cr, Ni, and Fe were higher in semen obtained from welders than in specimens from either controls or manganese workers. The time from ejaculation to liquefaction of semen in exposed workers was longer than that in controls, and semen volume, sperm count, viable sperm count and percent viable sperm were significantly lower in the exposed workers than in the controls. The data were analyzed by stepwise regression analysis and the investigators concluded that the results suggest that “manganese exposure has a toxic effect on sperm production.”

Tas et al. (Ref. 142) reviewed more than 400 published articles concerned with epidemiological and experimental findings regarding occupational hazards to the male human reproductive system. They summarized reported reproductive effects of exposure to physical agents (e.g., heat, radiation, noise), chemical agents, and heavy metals. Nine occupations reported to have adverse reproductive effects were also considered. Twelve studies about welders were cited and the findings tabulated according to the reproductive effects investigated (see Table 11). The single reported finding of spontaneous abortion (miscarriage) came from a study conducted by Bonde et al. in 1992 (Ref. 24) who later re-examined the data and refuted the original findings (Ref. 67).

Several metals that may be present in welding fumes were included in the discussion by Tas et al. of the reproductive effects of metals. Cadmium has been shown to cause testicular damage in laboratory animals, but only in high doses. Because epidemiological studies have not demonstrated an effect on semen quality or fertility, Tas et al. concluded that cadmium is unlikely to have reproductive effects in male workers. Manganese, through its effects on the nervous system, may produce a

Table 11
Summary of Studies Showing Positive and Negative Associations Between Paternal Welding and Reproductive Effects

	Number of Studies	
	Positive	Negative
Sperm abnormalities	3	1
Hormonal imbalance	—	2
Reduced fertility	2	—
Spontaneous abortion	1 ⁽¹⁾	—
Birth defects	—	2
Childhood malignancy	3	2

General Note: Data from Tas et al., Ref. 142.

Note:

(1) This positive result was refuted upon re-examination of the data (Ref. 67).

decreased libido and decreased sexual activity, but no strong evidence was found for an impact of manganese on other reproductive endpoints. Finally, Tas et al. pointed to evidence showing that paternal blood lead levels of 40 to 60 µg/dL blood may be associated with reproductive effects such as spontaneous abortions. In another review of reproductive disorders associated with occupational exposures, Paul (Ref. 112) cited evidence showing that lead has direct effects on the testes causing decreased sperm counts and aberrant sperm motility and morphology.

18.2 Birth Defects. Spina bifida is a birth defect in which the neural tube does not develop normally. The child is born with a defect in the spinal column through which spinal cord tissue may protrude. Blatter et al. (Ref. 20) conducted a case-control study of the association between parental occupation and spina bifida in offspring. The 353 cases were children with spina bifida selected from nine different hospitals in the Netherlands. The 1329 controls were randomly selected from municipal birth registries. All cases and controls were born between 1980 and 1992. Data concerning industry, occupational title, and daily occupational activities for both parents were collected using mailed questionnaires. The risk for producing a child with spina bifida was highest (OR = 5.6, CI = 1.8–17.8) for women working in agricultural occupations. For the fathers, increased odds ratios were found for welders (OR = 2.1, CI = 0.6–7.0) and transport workers (OR = 1.4, CI = 0.9–2.1), but the risks for producing a child with spina bifida were not statistically significant.

19. Effects of Specific Metals

19.1 Effects of Manganese. Chelation therapy with disodium ethylenediaminetetraacetate (EDTA) is the treatment of choice for lead poisoning, but it has not been successful in treating patients with manganese poisoning (Ref. 6). There is only a weak association between concentrations of manganese in urine (U_{Mn}) and blood (B_{Mn}) and the signs of Mn poisoning and although EDTA treatment may reduce U_{Mn} levels, it has only a minimal effect on clinical symptoms. Nonetheless, Angle (Ref. 6) tested the effects of another chelator, dimercaptosuccinic acid (DMSA), on blood and urine levels of B_{Mn} and U_{Mn} in two welders who had been chronically exposed to manganese. The first had been exposed to manganese at work for 19 years from the use of 18% manganese alloy welding rods during re-assembly of railway tracks containing 11–15% Mn alloy steel. The second had 30 years experience welding, cutting, and brazing a mild steel alloy containing 1–2% Mn. Both men had been treated with EDTA which resulted in increased levels of B_{Mn} and U_{Mn} . Following this, the men were treated for 14 days with DMSA. Urinary and blood manganese levels were measured before treatment, on the sixth day of treatment, and six days after treatment was completed. No changes were seen in B_{Mn} , but U_{Mn} increased in the second subject on the sixth day of treatment. Both men had had signs of manganese poisoning which were not relieved by these treatments. Angle concluded that “the negligible responses of B_{Mn} and U_{Mn} do not encourage trials of DMSA in manganese poisoning.”

19.2 Effects of Beryllium. Chronic exposure to low levels of air-borne beryllium can cause a progressive disease in which granulomas form in the lung which may not become apparent until long after exposure has ceased. The symptoms slowly progress to a severe and debilitating condition which eventually restricts the pulmonary transfer of oxygen into the blood. This condition, chronic berylliosis or chronic beryllium disease (CBD), can cause permanent lung damage and may be fatal.

Chronic beryllium disease (CBD) is diagnosed by characteristic changes in chest X-rays and by the identification of beryllium in biopsied lung tissue, lymph nodes, or urine. An *in vitro* immunologic assay, the lymphocyte proliferation test (LPT), can be used to detect hypersensitivity to beryllium which is thought to be one of the early signs of CBD. The LPT tests the ability of beryllium to stimulate the proliferation of lymphocytes taken from the peripheral blood or from BALF.

Using LPT, chest X-rays, and medical examinations, the prevalence of CBD and beryllium sensitivity was surveyed at the Rocky Flats Environmental Technology Site near Denver, Colorado (Ref. 139). Beryllium production operations began at Rocky Flats in 1957. The first case of

CBD at Rocky Flats was diagnosed in a machinist in 1984. By 1991, 23 additional cases were identified from a group of 954 tested. One of the cases was an employee with no identifiable exposure to beryllium which suggested that CBD may result from very low exposures to beryllium. After 1991, the testing program was expanded to include present and past employees and contractors who had worked at the plant. Of 1885 current employees tested, six were diagnosed with CBD and an additional 22 were found to be sensitized to beryllium. Of 2512 former employees, 22 were diagnosed with CBD and 47 were found to be beryllium-sensitive. Diagnostic tests for CBD had not been completed in the beryllium-sensitive group at the time this report was published. The authors noted that exposures could have occurred during foundry operations, casting, shearing, rolling, cutting, welding, machining, sanding, polishing, assembly, and chemical analysis operations but neither CBD nor beryllium sensitivity was specifically attributed to welding. They also noted that although the applicable safety exposure requirements for beryllium were maintained in the plant, beryllium sensitization and CBD still occurred. The authors concluded that the appearance of CBD or beryllium sensitization among administrative support personnel indicates that adherence to the TLV may be insufficient to prevent sensitization to beryllium.

19.3 Effects of Cadmium. Acute inhalation of high concentrations of cadmium can cause symptoms of metal fume fever but may also cause chemical pneumonitis, a potentially fatal condition in which pulmonary edema develops hours after exposure. Ando et al. (Ref. 5) described the case of a 43-year-old man who was exposed to cadmium fumes while working with silver solder in a large iron pot. He occasionally inserted his head into the pot without using any protective equipment, thus exposing himself to high concentrations of fumes. When he finished the job he had nausea, followed that night by difficulty breathing, chills, and fever. His symptoms continued to worsen and he reported to the hospital 3 days after the exposure with severe fatigue and difficulty breathing. He was initially diagnosed with metal fume fever on the basis of his history, even though it was unlikely because metal fume fever usually resolves within 24 hours after onset. His cadmium exposure was corroborated by the presence of cadmium in his urine which remained elevated for about 2 weeks after exposure. Urine analysis showed mild proteinuria and some renal tubular cells. His condition was diagnosed as transient renal tubular impairment which was attributed to cadmium exposure. By the fifth day following exposure, he developed pulmonary edema. He was treated symptomatically and his condition improved; he was released from the hospital after about 2 weeks.

19.4 Effects of Lead. The OSHA standard for lead was first established in 1971. In 1978, the general industry lead standard was revised; the permissible exposure limit (PEL) was reduced and biological monitoring of lead-exposed workers was required. In 1993, the OSHA interim final rule for protection of lead-exposed construction workers took effect, and the PEL was reduced from 200 μg to 50 $\mu\text{g}/\text{m}^3$ as an 8-hour time-weighted average to be consistent with the general industry standard. The new construction standard also includes medical examinations and biological monitoring which are required when air lead levels exceed the action level of 30 $\mu\text{g}/\text{m}^3$. Workers with blood lead levels greater than 50 $\mu\text{g}/\text{dL}$ must be removed from the job and monitored monthly until cleared for return. A study conducted from 1987 to 1993 by the California Department of Health Services demonstrated the effectiveness of proper work practices, respirator use, and personal hygiene techniques as well as the importance of biological monitoring to reduce the lead exposure of construction workers (Ref. 106).

Of the 1 million workers estimated by OSHA to have been occupationally exposed to lead in 1993, the 5.2% involved with bridge repair were considered to be at particular risk. The use of containment enclosures at these sites reduces the release of lead into the environment but increases the lead concentrations to which workers are exposed. Work associated with a high risk of lead exposure includes abrasive blasting, burning, welding, and cutting surfaces with lead based coatings (structures that had been covered with lead paints). Exposure may occur through inhalation of fumes or dusts and by ingestion of dusts. In addition, the families of workers may be incidentally exposed to lead by contact with clothing soiled on the job (Ref. 106).

In 1991, a collaboration among the Connecticut Department of Public Health, the Connecticut Department of Transportation (DOT), and NIOSH implemented a plan to reduce lead toxicity in bridge workers through the incorporation of protective measures which required monitoring and reduction of lead exposures at bridge sites and monitoring blood lead levels in workers into State contracts with construction companies (Ref. 29). Compliance with the "Lead Health Protection Plan" was enforced by routine DOT inspections to which the success of the program was, in part, attributed. Contractual requirements included personal and ambient airborne lead sampling, minimum standards for protective equipment, and standardized comprehensive medical monitoring. Blood lead levels were found to decrease substantially after the program was implemented in 1991. Two to threefold declines in blood lead levels were observed in painters/blasters and carpenters. For iron-workers/welders, average blood lead levels declined steadily from 20.6 $\mu\text{g}/\text{dL}$ in 1991 to 10.9 $\mu\text{g}/\text{dL}$ in 1994.

These results suggest that implementation of this contractually-required monitoring program by the State of Connecticut led to a marked reduction in the lead exposures of bridge workers. However, the promulgation of the new OSHA lead standard in May, 1993, which reduced the PEL for lead from 200 $\mu\text{g}/\text{m}^3$ to 50 $\mu\text{g}/\text{m}^3$ may also have made a strong contribution to the reduction of blood lead levels in these workers.

Hunaiti et al. (Ref. 72) determined the concentrations of lead in blood collected from 263 men residing in northern Jordan, some of whom had jobs in which they were potentially exposed to lead. The subjects were placed in five occupational categories and their blood lead concentrations compared (see Table 12). All of the workers had higher mean blood lead levels than were found in the 21 university students who served as controls and had no known lead exposures. The mean blood lead concentration was highest in metal casters (41.6 $\mu\text{g}/\text{dL}$ blood) followed by radiator welders (32.8 $\mu\text{g}/\text{dL}$). (For comparison, NIOSH has set a national goal in the U.S. of a maximum of 25 μg lead/dL blood.) The authors attributed the elevated blood lead levels to the inadequate use of safety equipment, lack of awareness of lead toxicity, and absence of lead screening programs in Jordan.

In addition to lead determinations, the levels of glutathione and the activity of several glutathione-dependent enzymes (glutathione reductase, glutathione peroxidase and glutathione S-transferase) were measured in red blood cells. The function of these enzymes is to protect tissues by scavenging free radicals. The concentrations of glutathione and the activities of the three glutathione dependent enzymes were found to be inversely related to the blood lead levels. The investigators attributed this to a reaction between glutathione with lead or with free radicals promoted by lead exposure.

Table 12
The Relationship Between Occupation and Blood Lead Levels in Workers in Jordan

Occupation	Number of Subjects	Blood Lead ($\mu\text{g}/\text{dL}$)
Metal casters	26	41.6
Radiator welders	22	32.3
Car painters	85	10.7
Mechanics	62	8.1
Bus drivers and gas station workers	47	7.6
Controls	21	5.7

General Note: Data from Hunaiti et al., Ref. 72.

20. General Health Effects

Kucheruk and Lubianova (Ref. 88) observed that Ukrainian welders, examined in an industrial health clinic, exhibited signs of premature aging. Using a protocol based on systolic blood pressure, pulmonary function, physical balance, and reported symptoms, they calculated the excess years of apparent age among welders. They found that the apparent or biological age was significantly greater than the chronological age for all of the welders, and the effect was exacerbated among those with pulmonary disease. For 35 welders, age 41–50 years, without pulmonary disease, the increase in apparent age was 11.5 years. The 60 welders, average age 44 years, who were diagnosed with bronchitis or pneumoconiosis, had an average apparent age 21.3 years greater than their actual age. Increased biological age was also associated with higher levels of total iron and transferrin-bound iron in the blood. The differences were statistically significant in all age groups and for welders with and without diagnosed lung disease. Levels of total blood iron and of transferrin-bound iron were higher in active welders than in former welders. In active welders, but not former welders, blood iron was higher among those with bronchitis than those with pneumoconiosis.

Tumor antigens are markers that appear on the surface of some tumor cells, or premalignant cells. In some cases, these markers are recognized by the immune system and circulating antibodies against them may be formed. Using immunological techniques, Lubianova and Novichenko (Ref. 94) tested for the presence of two organ-specific tumor antigens (OOAG and CEA) which, they stated, may appear on the surface of premalignant lung cells. For use in these tests, blood was drawn from the Ukrainian welders diagnosed with pneumoconiosis (18 subjects) or chronic bronchitis (34 subjects). Positive reactions to OOAG were found in 16.4% of the subjects with pneumoconiosis and 9.4% of those with bronchitis. The respective sensitivities to CEA were 2.0% and 5.2%. Positive reactions were more frequent among current welders than among those who had ceased welding, and the decrease in frequency was related to the number of years since last working as a welder. The authors concluded that these data show that the number of transformed, premalignant cells in the lungs is exposure-related and reversible. Increased levels of iron and transferrin in the blood were also found in the welders who showed sensitivity to the tumor antigens. This suggested to the authors that increased cancer risk among welders may be associated, not only with exposure to the carcinogenic metals nickel and hexavalent chromium, but also with the accumulation of iron. Further evidence cited by the authors for a role of iron in the development of cancer comes from increased prevalence of hepatocellular

carcinoma in patients with hereditary excess iron and from tissue culture studies in which tumor formation was induced by injection of iron.

Omokhodion and Osungbade (Ref. 105) conducted a questionnaire-based survey concerning work-related health problems, symptoms associated with the job, and the presence of chronic illness among 204 automobile mechanics and 96 workers in associated trades in a city in Nigeria. Following the administration of the questionnaire, the hands of each participant were examined for signs of dermatitis such as scaling, fissuring and blistering. The incidence of dermatitis was highest in the 50 workers classified as panel beaters and welders. Musculoskeletal disorders, particularly lower back pain, were the most common work-related health problems reported by the respondents and constituted the predominant health problems among automobile mechanics.

Ruegger (Ref. 127) reviewed claims for compensation for lung disease associated with metal working that had been reported to the Swiss National Accident Insurance Organization between 1987 and 1992. The average number of confirmed cases of metal fume fever in Switzerland during that period was about 16 per year. Most of these occurred among welders and cutters working in confined spaces on zinc-coated boilers and hot water heaters. Few claims were made for chronic lung disease associated with exposure to fumes from metal working. This was attributed to improved industrial hygiene practices and a decline in the metal processing industry. Ruegger reported no cases to date of bronchial tumors that could be ascribed to inhalation of metals in that country.

21. Case Report

Tvedt et al. (Ref. 150) described an incident in which a 36-year-old Norwegian shipyard worker was inside a carbon steel pipe, using GMAW with an argon shielding gas. The pipe was standing in a vertical position and had an internal diameter of about 26 inches. Fifteen to twenty minutes after returning to work from a break, he was found unconscious in a sitting position in the pipe. He regained consciousness a few hours later. In two days, he appeared to be in good health and was discharged from the hospital. However, he returned to the hospital one week later with confusion, failing memory, inability to speak, incoordination, and urinary incontinence. Examination by magnetic resonance imaging (MRI) suggested cerebral damage. Although he improved gradually and six months later was given less demanding work, the course of his illness continued to worsen. Two years after the accident, he had tremors in the right arm, difficulty reading and performing calculations, excessive fatigue, and reduced memory. Four years later, he showed little

improvement and was awarded a disability pension. The authors attributed his illness to hypoxia due to displacement of oxygen by argon.

22. Biological Monitoring

Matzcak et al. (Ref. 97) examined the relationship between chromium concentrations in urine and exposure to total chromium, Cr(VI), and Cr(III) in welding fumes. Fifteen welders from a chemical facility and two metal facilities (five per plant) for 2 to 27 years participated in the study. Four of the welders from the chemical facility used both SMAW and GTAW. The remainder of the welders used only SMAW. The study continued for a period of one week during which time all the participants welded a high alloy Cr-Ni stainless steel, containing 17–18% chromium. Urine samples were collected from each welder before and after the work shift for 5 consecutive days. Breathing zone samples were collected throughout the workshift on each of the days that urine samples were collected and the respirable fraction was analyzed for Cr(III) and Cr(VI).

Levels of Cr(VI) and Cr(III) were very low (less than 0.005 mg/m³) in the GTAW fumes. Hexavalent chromium in fumes from SMAW represented 33–56% of the total chromium, of which 87% was soluble; Cr(III) represented 44–67% of the total chromium and it was mainly insoluble (72%). The SMAW welders exposed to total chromium ranging in air from 0.05 to 0.2 mg/m³ had mean urinary chromium values of 17 to 58 µg/g creatinine. The levels of total chromium were highest in urine samples collected from the welders with the highest breathing zone concentrations of chromium.

The correlation between urinary and airborne chromium exposures was closest when the daily difference between the before and after shift urine chromium concentrations ($\Delta-U_{Cr}$) was compared with the chromium content of the fumes. The levels of total chromium in urine samples collected at the end of the work shift from SMAW welders correlated ($r = 0.015$, $p > 0.05$) with concentrations of soluble chromium compounds measured in the air samples collected during the same work day. The closest correlation between $\Delta-U_{Cr}$ and airborne chromium was seen for total chromium ($r = 0.58$), followed by total Cr(VI) ($r = 0.56$) and soluble Cr(III) ($r = 0.53$) in the air. The weakest correlations were seen for insoluble Cr(VI) ($r = 0.42$), total Cr(III) ($r = 0.42$), and soluble Cr(VI) ($r = 0.48$).

Matzcak et al. concluded that a more precise measure of exposure to chromium can be obtained by measuring the increase of urinary chromium during the workshift ($\Delta-U_{Cr}$) rather than by measuring it only at the end of the

work shift. They noted that soluble Cr(III) may make an important contribution to the chromium content of urine. They further concluded that exposure to 0.05 mg soluble Cr(VI)/m³ [the TLV for soluble Cr(VI) compounds] corresponds to urinary chromium values of about 30 µg/g creatinine and to an increase in urinary chromium during an 8-hour work shift of about 10 µg/g creatinine. These values would be applicable only to workers with about 7 or more years employment, as workers with fewer than 2 years employment were found to have lower values for $\Delta-U_{Cr}$. For the latter workers, values of 7 and 5 µg/g creatinine for urinary chromium and $\Delta-U_{Cr}$, respectively, were found during exposure to 0.05 mg soluble Cr(VI)/m³. The investigators speculated that the differences were due to increased renal chromium clearance rates in chronically exposed workers.

23. Biomarkers

23.1 Genotoxicity. Biomarkers are changes in biological characteristics or macromolecules that can be used to determine if exposure to occupational or environmental pollutants has occurred over time. Typical biomarkers are changes in the genetic material (DNA) in the form of sister chromatid exchanges (SCE) or chromosomal aberrations. Such changes could result from exposure to a wide variety of genotoxic or carcinogenic chemicals. SCEs and chromosomal aberrations are usually assayed in lymphocytes collected from the peripheral blood of test subjects.

Jelmert et al. (Ref. 77) examined the integrity of chromosomes in peripheral lymphocytes collected from 44 stainless steel welders, of whom 23 used GTAW and 21 used GMAW. Cytogenetic analyses were conducted with blood samples taken from each of the welders at the end of the work week. Results from individual welders were compared with those from referents matched by age, gender, and smoking habits. The welding group averages were compared with those from a larger reference group composed of 94 subjects who were primarily office workers and had no known exposures to metal fumes.

The incidence of gaps, chromatid and chromosome breaks, and the number of cells with chromosomal aberrations was lower in lymphocytes from welders than in those from referents. No differences were seen in the incidence of SCE between welders and nonwelders. The number of both chromatid and chromosome breaks was higher in smokers than in nonsmokers in both the welders and control groups.

Levels of chromium and nickel were measured daily in air samples collected from the breathing zone and in blood and urine collected periodically throughout the

work week in a subgroup of 14 of the GMAW welders and 17 of the GTAW welders. There was a statistically significant negative association between the incidence of SCE and concentrations of total chromium in inhaled air. A weaker negative correlation was found between the incidence of SCE and the concentration of Cr(VI) in inhaled air. No further associations were found between the biological parameters and concentrations of either nickel or chromium. The authors concluded that exposure to fumes from GTAW or GMAW with low levels of chromium and nickel is not associated with cytogenetic damage but, rather, appeared to decrease the prevalence of such changes in the exposed welders. They suggested that the decline in cytogenetic damage might be related to an enhancement of the DNA repair mechanisms associated with slightly elevated exposures to chromium.

De et al. (Ref. 39) compared the incidence of chromosomal aberrations in workers from a machine shop in India with that in unexposed controls. The machine shop workers included two machinists, three fitters, two welders, and two benders. The control group consisted of five males with no occupational exposures to metals and three office workers who had indirect exposures to metals. Blood samples were obtained from each of the study participants, and lymphocytes were scored for chromosomal aberrations. The frequency of chromosomal aberrations was significantly greater in the metal workers than in the controls. The increased chromosomal aberration frequency in metal workers was due to increases in the frequency of chromatid breaks. The authors concluded that combined exposures to metals and other agents in factory environments are able to induce chromosomal changes.

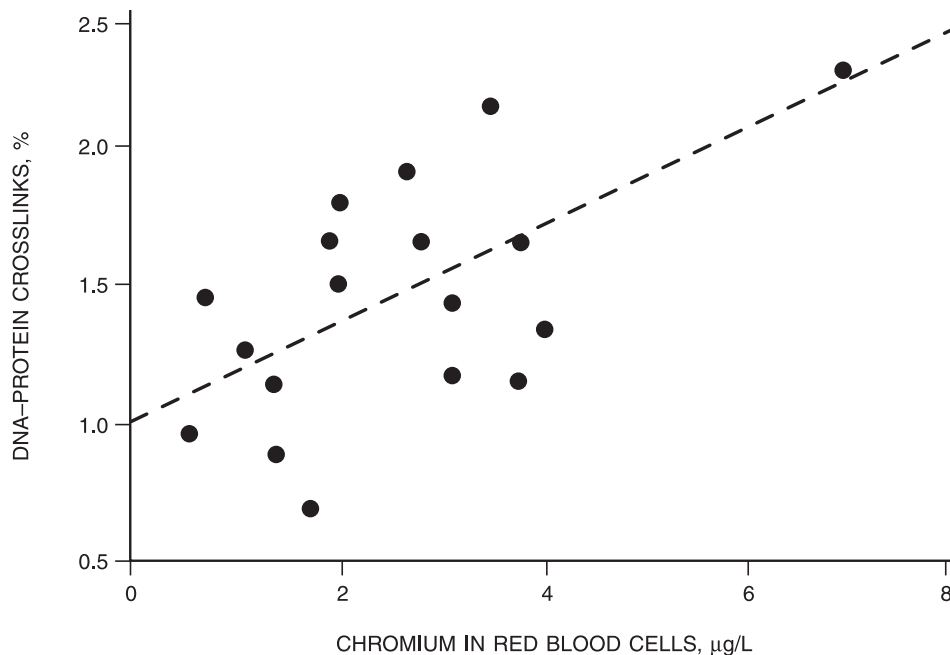
23.2 DNA-Protein Cross-Links. Hexavalent chromium compounds can induce respiratory cancers in experimental animals, are genotoxic and mutagenic in *in vitro* assays, and have been found by epidemiological studies to be associated with nasal and respiratory cancers in chrome plating and refinery workers. Cr(III) is much less toxic than Cr(VI), presumably because it is not readily transported into cells. Unlike Cr(III), Cr(VI) is actively transported into cells and the intracellular reduction of Cr(VI) to Cr(III) is thought to be ultimately responsible for the genotoxicity and carcinogenicity associated with exposure to Cr(VI). Chromium may exert genotoxic effects by binding directly to DNA. It can also cause cross-links to form between strands of DNA, between DNA and amino acids, and between DNA and proteins. Any of the resultant complexes can be used as indicators or biomarkers of exposure to Cr(VI) but, because they are the easiest to detect, DNA-protein cross-links are the most widely studied for this use.

In 1993, Costa et al. (Ref. 36) reported finding that railroad track welders had significantly more DNA-

protein cross-links in their peripheral white blood cells than did controls. However, they were not able to verify exposure to cross-linking agents since levels of blood and urinary chromium were the same in welders and controls. More recently, Costa et al. (Ref. 37) used three different study populations to test the hypothesis that environmental exposure to chromium can cause DNA-protein cross-links. The three populations were a group of Bulgarian chrome platers ($n = 14$) and subjects from two different Bulgarian cities, Jambol ($n = 11$) and Burgas ($n = 6$), which have high and low levels of air pollution, respectively. Chromium concentrations in red blood cells and urine, and DNA-protein cross-links in peripheral blood lymphocytes were determined in each study participant. Concentrations of red blood cell chromium, but not urinary chromium, correlated strongly with the levels of cross-links in lymphocytes from the subjects from Jambol and Burgas and from the chrome platers (see Figure 6). DNA-protein cross-links reached a maximum at red blood cell chromium concentrations of about 7 to 8 ppb. The investigators concluded that red blood cell levels of chromium correlate well with DNA-protein cross-links in lymphocytes.

23.3 Metals in Hair. Levels of metals in samples of scalp hair are occasionally studied as biomarkers of the occupational environment. Results of such measurements may be indicative of the environmental pollutants in the subjects' work and living environments. However, they are less sensitive than the genetic markers discussed above because the metals that were directly deposited on the hair cannot be distinguished from those that were first absorbed by the body before being incorporated into the hair shafts. Thus, a worker who is highly protected by a personal respirator may still have untoward quantities of metals deposited in his hair that would not necessarily be related to health risks.

Ramakrishna et al. (Ref. 122) compared the concentrations of 17 trace elements in hair samples collected from 22 industrial welders, 15 locomotive shed workers, and 21 controls (15 students and 6 office workers) who worked or resided in Nagpur, India. Potassium was the most significantly elevated metal in hair shafts from welders, with a mean value 181% above that in hair from controls. In welders, the levels of Ba, Co, Cu, Mn, Sc and Sb were also increased whereas Br, Cr, Hg, Se, Th, and Zn levels were decreased compared with controls. The trace elements in hair from locomotive shed workers differed from those in hair from welders. Concentrations of chromium and thorium were the most highly elevated elements in hair from shed workers; Sc, Na, Ca, Fe, Co, K, and Hg levels were also significantly elevated in hair from these workers compared with controls.



General Note: Chromium and DPC were measured in lymphocytes and red blood cells obtained from individuals residing in Burgas or Jambol, Bulgaria. Data from Costa et al., Ref. 37.

Figure 6—Correlation of Chromium in Red Blood Cells with Lymphocyte Levels of DNA-Protein Cross-Links (DPC)

Section Three Investigations in Animals and Cell Cultures

24. Effects of Welding Fumes on the Lungs

In studies in rats, Antonini et al. (Refs. 7 and 8) compared the inflammatory properties of different types of welding fumes and their potential to injure the lungs. The welding fumes tested were generated by conventional spray GMAW of stainless steel (SS-SPRAY) or mild steel (MS-SPRAY) or by pulsed current GMAW of mild steel (MS-PULSE). No significant differences were seen in the composition of fumes produced by MS-SPRAY or MS-PULSE (Table 13) or in the size of particles generated by the three processes.

Test particles were suspended in saline and introduced into the lungs of rats by intratracheal instillation (1.0 mg/100 g body weight). Controls received saline alone. The

effects of welding fumes were compared with those produced by ferric oxide (Fe_2O_3) particles, which are relatively inert, and with crystalline silica (quartz) which is highly toxic to the lungs. Rats were sacrificed at 1, 7, 14, and 35 days after treatment at which time the lungs were rinsed with saline to obtain bronchoalveolar lavage fluid (BALF). Inflammation and pulmonary damage were assessed by measuring the number of neutrophils and macrophages, concentrations of the cytokines tumor necrosis factor-alpha (TNF) and interleukin-1 beta (IL-1) and levels of the proteins albumin, lactate dehydrogenase, and beta-n-acetyl glucosaminidase in the BALF.

All of the test particles caused an elevation in the numbers of neutrophils in the BALF at 1 and 7 days after treatment and in the number of macrophages at 7 days after treatment. The number of these cells returned to normal by 2 weeks after treatment with ferric oxide and mild steel welding fumes but remained elevated in BALF from rats treated with silica and SS-SPRAY fumes until the end of the study (day 35). These results indicated that fumes from GMAW of stainless steel produce a longer-lasting inflammatory state in the lungs than do fumes

Table 13
Particle Size and Elemental
Composition of Welding Fume Samples

Sample ⁽¹⁾	Count Mean Diameter ($\mu\text{m} \pm \text{SE}$)	Metal Composition (% Weight)
SS-Spray	1.38 \pm 0.16	53.3% Fe, 2.3% Si, 18.3% Mn, 22% Cr, 4.9% Ni
MS-Spray	1.22 \pm 0.11	89.2% Fe, 2.6% Si, 8.2% Mn
MS-Pulse	1.23 \pm 0.12	88.6% Fe, 3.8% Si, 7.6% Mn

General Note: Data from Antonini et al., Ref. 8.

Note:

(1) No significant differences were observed in the size of the three welding fume samples; stainless steel-spray (SS-SPRAY), mild steel-spray (MS-SPRAY, and mild steel-pulse (MS-PULSE).

from GMAW of mild steel. Changes in the concentrations of the proteins albumin, lactate dehydrogenase, and beta-n-acetyl glucosaminidase also suggested that the stainless steel fumes are more damaging to the lungs than mild steel fumes, but much less so than silica particles. Temporal fluctuations in the concentrations of all three proteins followed a similar pattern (typified by that of beta-n-acetyl glucosaminidase shown in Figure 7). The proteins increased during the first 1 or 2 weeks after treatment with stainless steel fumes but subsided thereafter. In contrast, the concentrations of these proteins continued to increase for the full 35 days of the study in rats treated with silica. Mild steel fumes caused only minor fluctuations in protein concentrations.

Levels of the cytokines TNF and IL-1 were measured on the first day after treatment. They were significantly elevated only in the BALF from rats treated with SS-SPRAY and silica particles. These cytokines are important because they are released from alveolar macrophages as they engulf foreign particles and can have both beneficial and detrimental effects on the body. They are essential to the inflammatory and immune processes because they attract white blood cells into the area of foreign particles. However, cytokines also induce the growth of fibroblasts which can eventually cause fibrosis (scar tissue) to form in the lungs. TNF has also been postulated by Blanc et al. (Ref. 19) to be a mediator of metal fume fever.

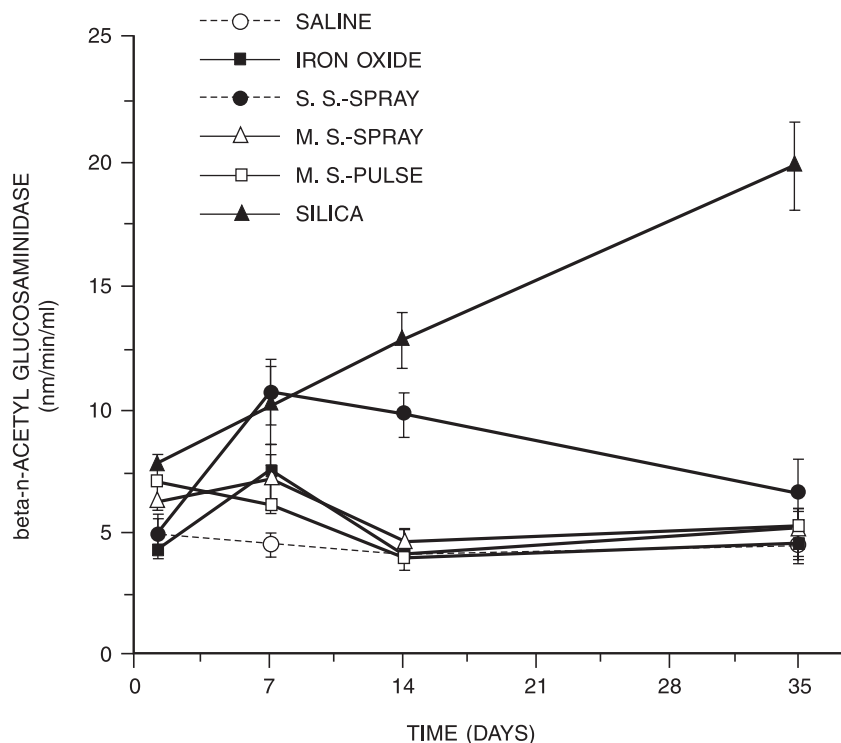
Finally, the investigators compared the rates of clearance of the SS-SPRAY and MS-SPRAY fumes from the lungs (Refs. 8 and 9). Using magnetometry and histological techniques, they found that MS-SPRAY fumes were cleared at a significantly faster rate than SS-SPRAY fumes. By 14 days after instillation, 36% of the mild steel particles, but only 8% of the stainless steel particles, had been cleared from the lungs. By 35 days, 74% of the

mild steel particles, but only 44% of the stainless steel particles were removed.

In summary, stainless steel welding fumes were cleared more slowly from the lungs, and induced a greater inflammatory response than did mild steel fumes. The investigators attributed the differences in retention and potential pneumotoxicity to differences in the chemical composition of the fume particles. They surmised that, because it appears that the stainless steel fume particles are eventually cleared from the lungs, measures taken to prevent exposure to stainless steel fumes could serve to protect against the development of chronic lung injury in already-exposed individuals. Since fumes from MS-PULSE and MS-SPRAY had the same composition and particle size distribution and elicited the same responses in the lung, the authors concluded that if pulse welding is associated with a reduction in fume generation, it should reduce the hazards to welders.

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General Note: Beta-n-acetyl glucosaminidase activity of the cell-free bronchoalveolar lavage fluid (BALF) from the lungs of rats 1, 7, 14, and 35 days after the intratracheal instillation of different welding fumes: stainless steel-spray (SS-SPRAY), mild steel-spray (MS-SPRAY), and mild steel-pulse (MS-PULSE). Silica (positive), ferric oxide (negative), and saline (vehicle) were used as controls. Values are means \pm SE. Data from Antonini et al., Ref. 8.

Figure 7—Comparison of beta-n-Acetyl Glucosaminidase Activity in Bronchoalveolar Lavage Fluid from Rats Treated with Mild Steel and Stainless Steel Welding Fumes

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