Effects of Welding on Health, XIII

American Welding Society

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Prepared for the
AWS Safety and Health Committee

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Abstract

This literature review, with 176 citations, was prepared under contract to the American Welding Society for its Safety and Health Committee. The review deals with studies of the health effects of fumes, gases, radiation, and noise generated during various welding processes. Section 1 summarizes recent studies of occupational exposures, Section 2 contains information related to human health effects, and Section 3 discusses the effects of exposures in animals.

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Foreword

This literature review was prepared for the Safety and Health Committee of the American Welding Society to provide an assessment of current information concerning the effects of welding on health, as well as to aid in the formulation and design of research projects in this area, as part of an on going program sponsored by the Committee. Previous work consists of the reports Effects of Welding on Health I through XII each covering approximately 2 to 3 years. Conclusions based on this review and recommendations for further research are presented in the introductory portions of the report.

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Glossary*

ACGIH	American Conference of Governmental Industrial Hygienists
BALF	Bronchoalveolar lavage fluid
CI	Confidence Interval
Cr(VI)	Hexavalent chromium
ELF- EMF	Extremely low frequency electromagnetic field
Dyspnea	Difficulty breathing; shortness of breath
Erythema	Reddening of the skin
FCAW	Flux cored arc welding
GMAW	Gas metal arc welding
GTAW	Gas tungsten arc welding
IgA	Immunoglobulin A
IgG	Immunoglobulin G
IgM	Immunoglobulin M
Leukocyte	White blood cell
LEV	Local exhaust ventilation
MAC	Maximum Allowable Concentration
MAL	Maximum Admissible Limit
n	Number
nm	Nanometer
NIOSH	National Institute for Occupational Safety and Health
NO	nitric oxide
OEL	Occupational exposure limit
OR*	Odds ratio
OSHA	Occupational Safety and Health Administration
PAH	Polycyclic aromatic hydrocarbons
PEL	Permissible Exposure Limit
PAC	Plasma arc cutting
PMN	Polymorphonuclear leukocyte
RR*	Relative risk
SIR*	Standardized incidence ratio
SMAW	Shielded metal arc welding
SMR*	Standardized mortality ratio
TLV	Threshold Limit Value
TWA	Time-weighted average
µm	Micrometer
µg	Microgram
UV	Ultraviolet

*Abbreviations for commonly used pulmonary function tests and for epidemiological terminology used in this document are found in Appendices A and B, respectively. The appendices describe the derivation of these terms and how they are used.

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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*. Twelve volumes have been published to date; the first covered data published before 1978, while the remainder covered 2-year to 3-year periods between 1978 and December, 1999. The current report includes information published between January, 2000 and December, 2002. 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 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 effects of welding on the respiratory tract continue to be examined and attention has been paid to the increased potency of respiratory tract infections in active welders. The number of investigations of the association of asthma with welding has increased as the prevalence of both occupational and non-occupational asthma increases in industrialized countries worldwide. As in the past, attention is focused on the incidence of lung cancer in welders. Four of the five studies conducted on lung cancer during this report period showed no statistically significant associations between welding and the incidence of this disease. Two reports showed that the effects on the skin and eyes of ultraviolet radiation from the welding arc can be exacerbated by the use of photosensitizing or photo-allergenic medications. The neurological effects of aluminum and manganese continued to receive attention during this report period.

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Executive Summary

Electromagnetic Radiation

Blue Light. Exposure to intense blue light in the visible range of 400 nm to 500 nm can cause photoretinitis with symptoms of decreased visual acuity, blurred vision, and scotoma (blind spot). Okuno et al. (Ref. 104) examined the blue-light hazard associated with GMAW, SMAW, and plasma arc cutting and found that the effective radiance increased with the welding current for both GMAW and SMAW. CO_2-shielded GMAW had the highest effective radiance of the arc welding and cutting procedures examined. The permissible daily exposure times for GMAW ranged from 0.63 to 2.7 seconds at different welding currents and those for SMAW ranged from 2.9 to 5.3 seconds. While plasma arc cutting was less hazardous than GMAW and SMAW, it still had a high effective radiance with a permissible exposure time of 10 seconds. Okuno et al. concluded that the arc welding and cutting processes examined are capable of producing photoretinitis with short exposures and considered them to be very hazardous to the retina.

Ultraviolet Light. Acute effects of exposure to ultraviolet (UV) light include erythema (reddening of the skin) and photokeratitis (welder's flash or arc eye). The symptoms of photokeratitis, a common injury among welders, include ocular pain, photophobia, and a sensation of sand in the eyes. Okuno et al. (Ref. 103) determined the effective radiance and corresponding permissible exposure time for UV light generated by CO_2-shielded FCAW and GMAW. The effective radiance was found to be inversely proportional to the square of the distance from the arc and varied with the angle, reaching a maximum between 50° and 60°, where the most intense UV radiation would be directed to the face when the worker assumes a typical welding position. At a distance of 1 meter from the arc, the permissible exposure time varied from 4 to 100 seconds depending on the welding current. Since welders are generally closer than 1 meter to the weld, the permissible exposure time would be lower than this and the exposures received by the unprotected eye would be higher. Okuno et al. noted that UV radiation may also present a hazard to nearby workers since, at a distance of 10 meters from the arc, the permissible exposure time measured under different test conditions ranged from 6 minutes to 3 hours.

In a similar study, Kozlowski (Ref. 71) determined effective radiances and safe exposure times for welding processes based on Polish Threshold Limit Values. For these studies, welding was conducted at currents that ranged from 40 A to 60 A and measurements were taken at 0.75 meters from the arc. A safe exposure time of 3 seconds was determined for daily exposures to argon-shielded GMAW. For SMAW, the safe exposure times ranged from 2.3 to 7.2 seconds for three different electrodes. Oxyfuel gas welding and cutting presented a much lower UV hazard as the respective safe exposure times were 2.5 hours and 1.43 hours.

Ventilation

The use of local exhaust ventilation (LEV) can reduce exposure to welding fumes, but its effectiveness varies with the type of LEV unit (Ref. 155), the upkeep of the LEV unit (Ref. 46), and the welding habits and posture of the welder (Ref. 157). Guffey and Simcox (Refs. 46, 132) demonstrated that, even when they are not well maintained, LEV systems can still offer some protection to the welder. They found that high individual exposures were usually attributed to welding posture, work practices, or improper use of the LEV device. Wallace et al. (Ref. 157) described an incident in which a welder, using an LEV device that was attached to the welding gun, moved the device upwards to avoid disturbing the weld. He had much higher exposures than another welder who, when using the same device, left the exhaust hood close to the weld but increased the shield gas flow to protect the weld. Wallace and Fishbach (Ref. 155) noted that local exhaust devices are less effective when welding is performed outdoors because of the disruption of air flow by natural wind currents. They suggested that the ability of the welder to stand upwind of the welding plume may be more important than the use of LEV.

Smargiassi et al. (Ref. 137) examined manganese exposures during welding operations in a factory where accessories for heavy excavation machinery were assembled.

Each welding station was equipped with a flexible-arm local exhaust and the welding guns all had integrated exhaust systems. Breathing zone concentrations of manganese varied substantially with the size of the part being welded. The TLV for manganese was exceeded in 78% of the total manganese samples collected during the assembly of large parts while none of the samples collected during the assembly of small pieces exceeded the TLV. The investigators attributed the significantly higher manganese exposures that occurred when welding large pieces to the semi-enclosed environment represented by the large buckets and scoops worked on in this factory and to the awkward postures that welders must assume when working on them. They noted that the exhaust systems integrated into the GMAW equipment used in this factory efficiently reduced dust and fume exposures only when the welder and the gun were properly positioned. Optimal fume collection occurs when the gun is positioned at 90° ± 15° with respect to the welding plane and when welders remain upright, keeping the welding plume out of their breathing zones. In semi-enclosed environments, positioning the gun correctly for effective exhaust was more difficult, and the welders of large parts were not always able to follow these guidelines.

In a NIOSH survey of exposures to toxic metals in a shipyard where scrapping, demolition, and dismantling of ships took place, Mattorano et al. (Ref. 87) observed that exposures to toxic metals were very high during welding in enclosed spaces where ventilation was achieved by blowing air into the tank through the workers' access portal. These investigators recommended that LEV should be used in addition to the dilution ventilation in use at the time of the survey. Wurzelbacher et al. (Ref. 164) showed that LEV produced about a 75% greater reduction of particulate exposure than did dilution ventilation during welding in barge hull assemblies that were open on one end. Local exhaust ventilation was produced by placing an air horn in the opening at the forward end of the barge hull assembly and drawing air through it via a small circular opening in the closed end. Dilution ventilation was accomplished by forcing air into the hull cell from the open end using an electric fan.

Effects on the Respiratory Tract

Asthma. Toren et al. (Ref. 150) estimated that 5% to 15% of adult-onset asthma may be caused by occupational exposures. Estimates of the occurrence of occupational asthma (OA) have varied from about 40 cases per million workers in a British survey, based on voluntary reporting by selected physicians, to 153 per million in Finland, where reporting of occupational diseases is mandatory. Toren et al. noted that an association between stainless steel welding and OA has been observed in some studies. Although the association between OA and welding of mild steel was less strong, the authors suggested that such a link might exist. Welders may also be exposed to triggers for asthma such as isocyanate monomers which can be liberated from polyurethane paints during welding of painted steel. A case in which asthma was attributed to phthalic anhydride and chlorendic anhydride released by welding of metal coated with a chlorinated polyester paint was described by Keskinen et al. (Ref. 68).

Karjalainen et al. conducted two studies of the incidence of OA in Finland. Using data retrieved from the Finnish Register of Occupational Diseases, they first examined the incidence of OA in a population of 1,107,586 male workers in Finland by occupation, industry, and causative agent (Ref. 63). During the 7-year period of the study, there were 1314 newly-reported cases of OA, with a mean annual incidence rate of 17 per 100,000. The annual incidence rate of OA among the 12,762 men in the occupational group designated as "welders, flame cutters, etc." was 76 per 100,000. Exposure to welding fumes accounted for 8.1% of the OA incidence in men. The authors noted that the national reporting system had an influence on these findings because cases associated with well-recognized causative agents are more likely to be compensated and, therefore, more likely to be reported.

In the second study, Karjalainen et al. (Ref 62) examined the incidence of OA among Finnish construction workers. Cases of OA were defined as men between the ages of 25 and 59 years, without pre-existing asthma, who received reimbursement for asthma medication from the Social Insurance Institution of Finland or were registered for compensation by the Finnish Register of Occupational Diseases. During the period of the study, 2548 cases of asthma were reported among the 108,549 construction workers. Of these cases, 45 had been recognized as OA. Fourteen were attributed to welding fumes which accounted for more cases of OA than any other exposures among construction workers.

In a study of the incidence of OA in Singapore between 1983 and 1999, Kor et al. (Ref. 69) identified 90 new cases. Isocyanate exposure was the causative agent in 31% of the cases, followed by soldering flux (13%), and welding fumes (9%).

Respiratory Tract Infections. Aviles et al. (Ref. 8) described the case of a 52-year-old man who had worked as a welder all of his adult life. He reported to the emergency room after 2 days of fever, rigors, cough, and shortness of breath. He was admitted to the hospital where he was diagnosed with streptococcal pneumonia.

He died within 24 hours after admission. This was his fourth bout of pneumonia within a 15-year period. The authors cited the work of Coggon et al. (Ref. 22) which showed that welders have an increased risk of dying from pneumococcal pneumonia. Neither the incidence of pneumonia nor the risk of dying from it remains elevated in welders after they retire. Aviles et al. postulated that the increased susceptibility to pneumonia in active workers may be related to toxic effects of inhaled fumes on alveolar macrophages or upon other aspects of the immune system.

Mizuhashi et al. (Ref. 93) described the cases of two welders with nontuberculous mycobacterial lung infections. Computed tomography of both men revealed mild cases of pneumoconiosis with deposits of welding particulate. Bacterial culture of sputum samples indicated Mycobacterium avium infection in one of the welders and Mycobacterium kansasii in the other. Both patients recovered after extensive treatment. The authors noted that nontuberculous mycobacterial lung infection is a rare complication of pneumoconiosis. They cited the work of Gomes et al. (Refs. 43, 44) which showed that, in mice, the intracellular bactericidal activity of macrophages against Mycobacterium avium is reduced in the presence of excessive iron. Based in part on that work, Mizuhashi et al. postulated that the ingestion of inhaled iron oxide particles by macrophages may affect the body's defense against mycobacterial infection, altering its clinical features and encouraging the development of infection.

In 2001, the Norwegian Labor Inspection Authority issued a warning to physicians about the potential severity of pneumonia in men exposed to welding fumes (Ref. 160). They recommended that patients with pneumonia who had welding exposures should be hospitalized because, while pneumonia is not usually lethal in middle-aged men unless there is some underlying disease, the inhalation of welding fumes may seriously aggravate the prognosis for this disease.

Cancer

Lung Cancer. Five studies examined the association between welding and the risk of lung cancer. Four of these studies showed no statistically significant associations (Refs. 26, 47, 113, 138) while the fifth (Ref. 106) showed a positive association but there may have been some confounding factors. In the mortality study by Steenland (Ref. 138), mild steel welders had a non-significantly greater proportion of deaths from lung cancer than did non-welders. Differences in smoking rates were likely to have accounted for at least part of the increased lung cancer incidence among welders; there was no relationship between the risk of death from lung cancer and the duration of welding exposure. (A positive exposure/ response relationship would have strengthened the likelihood of a causal relationship between the exposure and the disease.) Gustavvson et al. (Ref. 47) conducted a case-referent study in Stockholm County, Sweden, that included 1042 men with lung cancer. The relative risk for lung cancer was not elevated among men exposed to welding fumes. The investigators concluded that their study did not provide evidence for an association of lung cancer with mild steel welding which, they stated, is the predominant type of welding used in the Stockholm area. Danielsen et al. (Ref. 26) investigated the incidence of lung cancer in a cohort of 4480 workers, including 861 welders, from a Norwegian shipyard. The welders had used GMAW and GTAW of stainless steel after the mid-1970s and SMAW of mild steel before that time. There was a small, non-significantly elevated incidence of lung cancer among the welders which was not related to the duration of the welding experience. Non-significant increases in deaths from lung cancer were also observed among welders by Puntoni et al. (Ref. 113) in a historical cohort mortality study that included 3959 workers from a shipyard in the harbor of Genoa, Italy.

In a case-control study designed to evaluate the utility of medical insurance claims records for investigating possible associations between occupational exposures and development of chronic disease, Park (Ref. 106) analyzed data provided by the United Auto Workers for workers from eight machining plants of an American automobile manufacturer. Welding was found to be significantly associated with an increased risk for lung cancer among those who had begun welding at least 25 years prior to filing their first claim for lung cancer. These data were confounded by various issues including a great variability between the eight participating plants which could not be explained by inter-plant differences in age, gender, or exposures, and the finding that the total number of lung cancer cases taken from the medical insurance claims was more than four times greater than that expected from cancer incident rates in Michigan where half of the plants included in the study were located.

Cancer in Organs Other Than the Lung. In their historical cohort mortality study of workers from a shipyard in the harbor of Genoa, Italy, Puntoni et al. (Ref. 113) found that deaths from kidney cancer were non-significantly elevated among electric arc welders and gas welders, when the two groups were considered separately. When the data from the two groups of welders were combined, the increase in the number of deaths from kidney cancer became statistically significant. In a multicenter population-based case-control study, Pesch et al. (Ref. 108) examined associations between renal cell carcinoma (RCC), the most common form of kidney tumor, and occupational exposures. The study was conducted in five regions of Germany and included 935 cases (570 men and 365 women) diagnosed with RCC between 1991 and 1995 and 4298 controls (2650 men and 1648 women). The risk of RCC was significantly elevated among women, but not men, with long durations of employment in an occupational grouping that included soldering, welding, and milling. Because welding was not examined independently, no conclusions can be drawn from this study about the risk of RCC among welders. Using tumor samples collected during a multinational case-control study of risk factors for RCC that showed no association between kidney cancer and welding (Ref. 82), Hemminki et al. (Ref. 51) examined the relationship between occupational exposures and mutations in the von Hipple-Lindau gene, a tumor suppressor gene known to be associated with RCC. A statistically significant increase in the number of cases with multiple mutations was associated with exposure to welding fumes alone among the occupational exposures examined in this study (e.g., asbestos, solvents, petroleum products). While molecular epidemiology studies of this nature are useful for studying mechanisms and exploring etiologic associations, they are limited in that they may also detect mutations that are not necessarily related to tumor development.

Alguacil et al. (Ref. 3) conducted a case-control study based on job titles to explore possible contributions of occupational exposures to the rising incidence of pancreatic cancer in Spain. They found a slight, non-significantly elevated risk of pancreatic cancer among workers who had been employed as sheet-metal workers, blacksmiths, welders, structural metal workers, toolmakers, or machine-tool setter-operators.

In case-control studies which explored occupational associations with two types of rare tumors of the small intestine, Kaerlev et al. found that welders have a non-significantly increased risk of developing small bowel carcinoid tumor (Ref. 60) and that welders and flame cutters have a statistically significant increased risk of developing small bowel adenocarcinoma (Ref. 61). Small bowel adenocarcinoma was significantly associated with GMAW but not with GTAW, SMAW, or plasma arc welding. The investigators stated that these studies were exploratory and the results should be regarded as tentative and in need of further investigation.

To examine the contribution of occupational and environmental exposures to non-Hodgkin's lymphoma (NHL), Zheng et al. (Ref. 172) combined and analyzed data from two previously published population-based case-control studies and found that the risk of NHL was significantly elevated and exposure-related in welders and solderers. Because the data for welders and solderers were combined, it is not possible to evaluate the risk of NHL among welders from this study.

Guenel et al. (Ref. 45) examined the role of occupational UV exposure in the development of ocular melanoma. They found that occupational exposure to artificial UV, but not to solar radiation, was a risk factor for the development of ocular melanoma, and a significantly increased incidence of ocular melanoma was found in men in the job category welders and sheet metal workers. The investigators concluded that welders have an elevated risk of ocular melanoma.

Population-based case-control studies revealed no association between parental occupation as a welder and the development of childhood brain tumors (Ref. 23). This study did not confirm previous findings by other investigators (Ref. 162) that showed a possible association of childhood brain tumors with welding.

Two recent studies of the cancer risk associated with extremely low frequency electromagnetic fields yielded conflicting results. In the first, a case-control study of the risks of acute leukemia in electrical workers, Bethwaite et al. (Ref. 11) found a significantly increased risk for leukemia with a positive exposure/response relationship among workers in the occupational categories electric welders/flame cutters and telephone line workers. In the second study, Hakansson et al. (Ref. 48) investigated the cancer incidence in a large cohort of resistance welders and found a significantly elevated risk for cancer of the kidney among male subjects and an increase in brain tumors among female subjects. The incidence of leukemia was not significantly elevated.

Metal Fume Fever

Copper fume is often cited as a cause of metal fume fever, but a report by Borak et al. (Ref. 15) raised questions about this association. Borak et al. searched the international literature and found insufficient evidence in humans to support an association between metal fume fever and exposure to copper fumes or dust and concluded that, if metal fume fever does result from exposure to copper fumes, it must be very rare. The investigators noted that occupational exposure limits for copper are based on a single report published in 1968 by Gleason (Ref. 42). They found Gleason's report of an acute upper respiratory illness in workers polishing copper plate to be inadequate proof that copper causes metal fume fever because the affected workers lacked symptoms typical of this condition and did not develop tolerance following repeated exposures. In addition, exposures were to mixtures of aluminum oxide and copper dusts, and copper could not be isolated as the cause of the symptoms.

Effects on the Ear

Five patients with hearing loss resulting from welding spark injuries of the middle ear were described by Kupisz et al. (Ref. 74). Three of the patients had sought medical help within 2 months of their injury and showed hearing improvement within 3 months after iron filings were removed surgically. The other two patients waited 4 years before seeking medical assistance. The long-lasting presence of a metal filing in the middle ear spaces of these two patients led to a chronic inflammatory process with progressive hearing loss. Kupisz et al. stressed that persons sustaining a middle ear injury caused by a welding spark should have surgical treatment within, at most, 2 to 3 months after the injury because the expeditious removal of a foreign body from the middle ear spaces improves the results of surgery and the chances for regaining hearing.

Effects on the Nervous System

Effects of Aluminum. Riihimaki et al. (Ref. 119) examined the relationship between central nervous system function and aluminum concentrations in serum and urine in 59 welders who exclusively performed GMAW of aluminum and in 25 mild steel welders who served as referents. Based on the median concentrations of aluminum in their urine and serum, the subjects were divided into three groups: no exposure, low exposure, and high exposures. Welders in the high exposure group had significantly more symptoms of fatigue, emotional lability, memory loss, and difficulties in concentration and performed significantly less well than controls in neuropsychological test batteries. Mild to moderate EEG abnormalities were more common in the high-exposure group than in the low-exposure group and were not found in the controls. The median concentrations of aluminum were 0.4, 1.8, and 7.1 μmol/L urine and 0.08, 0.14, and 0.46 μmol/L serum for the no, low, and high exposure groups, respectively. Based on these data, the investigators estimated that aluminum concentrations of 4 μmol/L–6 μmol/L in urine and 0.25 μmol/L–0.35 μmol/L in serum represent the threshold for multiple adverse effects in aluminum welders.

Bast-Pettersen et al. (Ref. 10) compared neurobehavioral/neuromotor function of 20 aluminum welders with that of an equal number of age-matched construction workers. Welders reported significantly more neurological symptoms than did controls, but the incidence of subjective symptoms was lower than expected based on clinical standards. Reaction times in computerized tests of both welders and controls were considered to be good compared with clinical standards. The welders, as a group, performed significantly better than did the construction workers in tests of hand steadiness, but a significant positive correlation was found between the duration of the welding experience and hand steadiness. The investigators concluded that while the results of the neurobehavioral tests did not show an effect of aluminum exposure, the correlations between extent and duration of aluminum exposures and hand steadiness suggested slight effects from aluminum exposure. The median urinary aluminum concentration of 1.86 μmol/L for welders in this study was below the threshold for multiple adverse effects in aluminum welders estimated by Riihimaki et al. (Ref. 119).

Effects of Manganese. McDonnell et al. (Ref. 89) searched the national pension fund archive of death certificates and occupational records for employees from a major British automobile manufacturer to examine the association of Parkinson's disease with exposure to metals or solvents. The risk for Parkinson's disease was nonsignificantly elevated among those who had been exposed to metals and it was not associated with the duration of exposure to metals.

Sinczuk-Walczak et al. compared nervous system function in 75 manganese-exposed Polish workers (62 shipyard welders and fitters and 13 battery production workers) with that of 62 non-exposed age-matched controls (Refs. 133, 134). The manganese-exposed workers reported emotional irritability, impaired memory, difficulty concentrating, sleepiness, and paresthesia (abnormal spontaneous tingling or burning sensations) in the extremities significantly more often than did controls. However, the occurrence of these symptoms was not significantly related to the manganese exposures measured during the study period or to the cumulative exposure index. Neurological examination and electroencephalograms revealed no significant differences between exposed workers and controls. Tests of visual evoked potential revealed abnormalities that could be indicative of subclinical optic nerve disorders. These findings were significantly related to the cumulative exposure index. The investigators concluded that manganese exposures at or slightly above the MAC value may cause subclinical effects on the nervous system.

Effects on Reproduction

In a case-control study that examined the influence of occupational exposures on male fertility, Sheiner et al. (Ref. 129) found that men with male fertility problems were significantly more likely to be working in industry and construction than were controls. No significant differences were found between cases and controls when exposures to welding, noise, and other physical and chemical agents were compared.

In a retrospective study of occupations associated with male infertility using data archived at their fertility clinic, Kenkel et al. (Ref. 67) found that the percentage of men in the occupational group metal workers/welders was non-significantly lower among men in the clinic than among men in the general population. Farmers and painters/varnishers were the only occupational groups to show significant reductions in sperm count and concentration. Metal workers/welders was the only group to show a significant decrease in sperm motility.

Auger et al. (Ref. 7) conducted a multicenter study to investigate the effects of environment, life style, and occupational factors on sperm morphology among 1001 men from four European cities. The number of sperm defects and abnormalities varied significantly with the city in which the participants resided, and more abnormalities were found in the spring than in the winter. Several sperm defects were significantly associated with stress, the number of hours worked per week, and with occupation as a welder. Two specific types of sperm defects were significantly more prevalent among the 15 subjects who had welded daily during the 3 months before the analysis compared with the 838 subjects who had never welded during this period. Since none of the participants in the study had experienced fertility problems, the biological significance of these observations is not known.

Tielemans et al. (Ref. 149) investigated whether male occupational exposures can influence the implantation of embryos in 726 couples undergoing *in vitro* fertilization. Implantation rates were measured by the number of gestational sacs divided by the number of transplanted embryos observed by ultrasound 6 to 7 weeks after embryo transplantation. The probability of implantation was not affected by paternal exposure to metal dusts or welding fumes.

Photosensitivity

Mauget-Faysse et al. (Ref. 88) described the case of a 73-year-old man who developed blurred and distorted vision in his left eye after inadvertent exposure to an electric welding arc that was approximately 3 meters from the left side of his body. Ophthalmologic examination revealed lesions on the macula of his left eye. Exposure to the arc was deemed to have been insufficient to have caused these lesions under normal circumstances and they were attributed to his use of the diuretic quinapril for hypertension and allopurinol for hyperurecemia at the time of his exposure. Both drugs are photosensitizers. His symptoms gradually improved and his vision returned to normal within a year.

The case of a welder who developed erythema and burning of his face after welding was described by Wagner et al. (Ref. 153). The skin lesions gradually worsened and he developed eczema on his face, neck, and forearms. He experienced an intense burning sensation following exposure to sunlight and while welding, even though he used a sunscreen and wore goggles and a welding shield while welding. He sought treatment for this condition from a dermatologist who found that he had developed photo-allergies to the two medications, hydrochlorothiazide and ramipril, that he had been taking for hypertension. He had started using these medications about 9 months before he began to experience skin reactions to welding and sunlight. Both drugs caused strong positive reactions in photopatch tests following irradiation with UVA but not with UVB or visible light. A change in his medication to a different anti-hypertensive drug and treatment with topical corticosteroids led to a complete resolution of his skin problems.

Munnoch et al. (Ref. 96) used laser therapy to treat a skin lesion on the cheeks of a 24-year-old man. Following the treatment, the patient was instructed to use factor 25 sunscreen because exposure to the sun could cause pigmentation of the treated area of the skin. Despite his use of a sunscreen, his cheeks became severely hyperpigmented within 6 weeks. At that time, the physicians learned that the patient was a welder and that he used GMAW exclusively. They attributed the hyperpigmentation to the high levels of UVC radiation that are generated by GMAW and explained that sunscreens provide protection against UVA and UVB, but not against UVC.

Technical Summary

The Exposure

Fume Composition

Saito et al. (124) used an automatic welding robot to compare fumes and gases released from three different consumable electrodes during GMAW with a carbon dioxide (CO_2) shielding gas. The proportion of manganese in the fumes was approximately eight times its proportion in the consumable electrodes from which it was generated.

Using a laboratory furnace to simulate workplace brazing conditions, Zimmer and Biswas (Ref. 175) compared the aerosols produced using a self-fluxing brazing alloy (89% copper, 6% silver, 5% phosphorus) with and without a supplemental fluxing compound (boric acid, potassium fluoride, and water). In the absence of the supplemental fluxing compound, the aerosols formed were transient and were composed of phosphorus compounds. When the fluxing compound was added, the concentration of fumes was magnitudes higher and consisted mainly of metal fluoride compounds. In later work, Zimmer (Ref. 174) found that the particles from Ar-CO_2 shielded GMAW of a 97%–98% iron alloy were homogeneous chain-like aggregates, while those produced by FCAW were heterogeneous, consisting of chain-like and spherical structures.

In 1995, Dennis and Mortazavi (Ref. 32) reported that ozone emission during GMAW could be substantially reduced by using a modified welding gun that produced two concentric argon gas shrouds, with the internal shield containing 5% CO_2 and the outer shield containing 300 ppm nitric oxide. More recently, these investigators (Ref. 31) found that, while an outer shield of argon containing nitric oxide or ethylene substantially reduced ozone levels, these outer shields were not effective in reducing Cr(VI). In another study, Dennis et al. (Ref. 30) showed that replacing potassium with lithium in a self-shielding flux cored electrode reduced the fume formation rate and the levels of Cr(VI) in fumes.

Analytical Procedures

Chromium. Scancar, Milacic, and Tusek (Refs. 92, 125) explored the use of anion-exchange fast protein liquid chromatography (FPLC) and convective-interaction media fast-monolithic chromatography (CIM) for quantification of Cr(VI) in welding fumes. FPLC was field tested with fumes generated by GTAW of stainless steel, and both systems were tested with samples collected during plasma arc cutting of stainless steel. Overall, the accuracy and reproducibility of CIM and FPLC were equivalent but the CIM procedure was twice as fast.

Thorium. Holmes and Pilvio (Ref. 57) investigated the use of inductively coupled plasma mass spectrometry (ICP-MS) for determining thorium concentrations in environmental materials. They concluded that ICP-MS is a powerful technique for detection and measurement of natural thorium.

Electromagnetic Radiation

Blue Light. Okuno et al. (Ref. 104) determined the blue-light effective radiance and corresponding permissible exposure time for GMAW, SMAW, and plasma arc cutting. They found that the intensity of the blue light generated by the arc welding and cutting processes examined is capable of producing photoretinitis with short exposures.

Ultraviolet Light. Using a welding robot under laboratory conditions, Okuno et al. (Ref. 103) measured the effective radiance and calculated permissible exposure times for UV light generated by CO_2-shielded FCAW and GMAW. The effective radiance was found to be inversely proportional to the square of the distance from the arc and varied with the angle, reaching a maximum at 50° to 60° from the plate surface. At a distance of 1 meter from the arc, the permissible exposure time varied from 4 to 100 seconds, depending on the welding current, indicating that the welding procedures studied present a radiation hazard to the eyes and skin.

Kozlowski (Ref. 71) determined effective radiances and safe exposure times for UV light generated by welding processes based on Polish Threshold Limit Values. At currents that ranged from 40 A to 60 A at 0.75 meters from the arc, safe exposure times of 2.3 to 7.2 seconds were determined for daily exposures to argon-shielded GMAW or SMAW with three different electrodes. For oxyfuel gas welding and cutting, the respective safe exposure times were 2.5 hours and 1.43 hours.

Incidental Exposures

Lead. Brumis et al. (Ref. 20) measured breathing zone lead exposures of a worker who was cutting steel on a bridge that had been coated with paint that contained 4.2% lead. The worker's 8-hour TWA lead exposure for 2 consecutive days of monitoring was determined to be approximately 80 times the OSHA Permissible Exposure Limit (PEL) of 50 $\mu g/m^3$. The investigators attributed the high lead exposure to improper preparation of the steel surface before cutting.

Phosgene. Nieuwenhuizen and Groeneveld (Ref. 99) measured the concentrations of phosgene formed when welding was conducted in an enclosed laboratory chamber containing known concentrations of vapors of each of four chlorinated hydrocarbons. From this work, they estimated that during the use of one SMAW electrode for 1 minute in the workplace, the short-term Maximum Allowable Concentrations (MAC) of 0.1 ppm for phosgene would not be attained at air concentrations of dichloromethane or carbon tetrachloride equivalent to their MACs. However, the short-term MAC for phosgene would be attained at concentrations much lower than the MACs for trichloroethylene and chlorodifluoromethane.

Isocyanates. Air sampling strategies for the determination of airborne isocyanates and related compounds formed during the thermal degradation of polyurethane in workplace environments were evaluated by Karlsson et al. (Refs. 64, 65) and Henriks-Eckerman et al. (Ref. 53). Henriks-Eckerman et al. (Ref. 52) found that concentrations of isocyanates in breathing zone samples collected for 3 to 30 minutes during grinding and welding operations in car repair shops and during welding and cutting of MDI-based PUR-insulated district heating pipes as they were being installed (Ref. 52) of isocyanates were less than the Finnish short-term occupational exposure limit (OEL) for di- and triisocyanates of 35 $\mu g/m^3$. Exposure to airborne diisocyanates was also assessed in urine samples collected from workers who participated in the air sampling studies (Ref. 120). Concentrations of TDI and MDI, measured as their respective metabolic products, toluenediamine and methylenedianiline, were 2 to 4 times higher in urine of car repair workers than in urine of controls. Welders of district heating pipes insulated with MDI-based PUR excreted about 30 times more MDI than did controls.

Workplace Exposures

Wallace et al. (Ref. 156) compared breathing zone exposures to fumes during pulsed arc and conventional GMAW at an agricultural and construction equipment manufacturing plant. Overall, the use of pulsed arc GMAW led to a statistically significant 24% reduction in welding fume concentrations. However, the manganese concentrations in the fumes generated by the two techniques did not differ.

Mattorano et al. (Ref. 87) measured exposures to toxic metals during demolition, scrapping, and dismantling of ships. Three workers used SMAW to install new materials inside barge tanks. The TLV for manganese was exceeded by more than eight-fold and that for lead was exceeded by about seven-fold in some personal samples collected during this process. Exposures were highest during oxypropane cutting, which was used to cut scrap metal and to remove nonferrous metal from the engine room of a ship. TLVs and PELs for lead, cadmium, and copper were all exceeded in samples collected during these processes. Breathing zone concentrations of lead and cadmium were found to be as high as eight and ten times their PELs.

Korczynski (Ref. 70) assessed the levels of noise, fumes, ozone and carbon monoxide in eight welding companies in Manitoba Canada. Personal exposures to noise measured for 44 of the 124 welders employed at these companies ranged from 79 dB(A)–98 dB(A) with a mean of 89 dB(A), which is in excess of the 80 dB(A) action level standard for an 8-hour day in Manitoba. Sixty-two percent of the welders had exposures to manganese greater than the TLV of 0.2 mg/m^3, and 19% had exposures to iron greater than its TLV of 5.0 mg/m^3.

Woskie et al. (Ref. 163) examined exposures to welding fumes among workers involved in the Boston Central Artery/Tunnel Project. Welding fume exposures occurred primarily in partially enclosed environments during excavation support operations when steel cross beams were welded in place. Welding fume concentrations equaled or exceeded the TLV in 17 of the 22 personal samples collected during SMAW of mild steel. Two samples exceeded the TLV for fluoride and three of the samples had manganese concentrations equivalent to the TLV.

In a series of studies, Matczak and Gromiec measured exposures to aluminum, copper, and gases produced by welding of aluminum, copper, and steel, respectively

(Refs. 84, 85, 86). The first study (Ref. 84) assessed exposures of aluminum welders to welding fumes and their major elemental components. During GMAW, the mean breathing zone fume concentrations were 8.8 mg/m^3 and 5.0 mg/m^3 in each of two plants, while the mean breathing zone fume concentration associated with GTAW fumes, measured in a third plant, was much lower (0.17 mg/m^3). The next study assessed exposure of copper welders to total fumes and to soluble and insoluble copper generated by SMAW and plasma arc welding (Ref. 86) and the final survey (Ref. 85) evaluated exposures of welders of mild and stainless steel to the gases NOx, CO, CO_2, and O_3. The TWA concentrations for all gases were below their respective MACs but some excursions above short-term exposure limits were seen.

Kucera et al. (Ref. 73) examined workplace exposures of 20 workers involved with welding, polishing, drilling and assembling of austentitic stainless steel constructions in the Czech Republic. The median breathing zone concentration of chromium exceeded the maximum admissible limit (MAL) of 50 μg/m^3 for 67% of the welders and 44% of the polishers. The MAL for nickel was exceeded in breathing zone samples from 33% of the polishers but in none of the samples from other workers.

Susi et al. (Ref. 145) evaluated aerosol exposures of 63 construction workers using welding and thermal cutting techniques at nine construction sites located throughout the U.S.A. When the data were examined by trade, the exposure to total particulate was highest for boilermakers, followed in descending order by ironworkers and pipefitters. Seventy-two percent of the samples from the boilermakers, 15% of those from the ironworkers, and 7% from the pipefitters exceeded the TLV for manganese.

Smargiassi et al. (Ref. 137) examined manganese exposures during welding operations in a factory in Quebec where accessories for heavy excavation machinery were assembled. The TLV for manganese was exceeded in 78% of the breathing zone samples collected during the assembly of large parts but in none of the samples collected during the assembly of small pieces.

Hygiene and Work Practices

Ventilation. Wurzelbacher et al. (Ref. 164) showed that local exhaust ventilation (LEV) was much more effective than dilution ventilation during welding in confined spaces in a shipyard. In studies conducted with a welding robot in an enclosed chamber, Ojima et al. (Ref. 101) showed that air duct ventilation did not effectively remove welding fumes from the breathing zone during a 6-minute period of welding within a confined chamber, but it was effective in exhausting residual contaminants after welding had ceased. Additional studies with this laboratory apparatus demonstrated that placing an exhaust hood at the height of the welder's breathing zone was more effective in reducing fume concentrations in the breathing zone than was placement of the hood near the weld (Ref. 130). Wallace and Fischbach (Ref. 155) tested two types of local exhaust units and found that one of them could effect an 80% decrease in fume exposure during SMAW of stainless steel. In the absence of ventilation, the welder's posture during welding was shown to be an important determinant of breathing zone exposures. In a separate study, Wallace et al. (Ref. 157) compared exposure levels during FCAW of carbon steel and GMAW and GTAW of stainless steel in a plant that manufactured commercial steam ovens. The investigators concluded that the welding method is the most important factor in determining welding fume exposures. Secondary factors are the composition of the base metal, the welder's position relative to the fume, and the type and effectiveness of the LEV.

Guffey and Simcox et al. (Refs. 46, 132) evaluated the effectiveness of newly installed LEV systems that had been designed to reduce exposures to cobalt and cadmium in a hard metal tool re-sharpening shop. Even though air flows generally declined due to poor maintenance over the 12 months of the study, cobalt and cadmium exposures dropped substantially for most of the workers after LEV was installed. Most cases where worker exposure was not satisfactorily controlled were attributed to improper use of the exhaust hoods or contamination from nearby, poorly ventilated automated machinery. Niemela et al. (Ref. 98) investigated the performance of displacement ventilation in a large industrial hall where FCAW and automatic welding machines were used in the manufacture of stainless steel furnaces and cylindrical tanks. The displacement ventilation was shown to effectively protect workers who were not actively welding, but workers frequently received excessive exposures when welding in stagnant areas or enclosed spaces.

Compliance with Health and Safety Regulations. Walls and Dryson (Ref. 158) audited the compliance with health and safety legislation in New Zealand by companies that carried out welding. The overall finding was that non-compliance was prevalent regardless of company size. In particular, control of welding fumes by local exhaust ventilation was used by less than half of the companies, and one-third of the companies had a satisfactory system for welding in confined spaces.

Accidents. In a cross-sectional survey in Pakistan, Shaikh (Ref. 128) found that 63 of 208 welders sustained injuries during the period of 1 year. The most common types of injuries were burns on the face, limbs, or trunk, and foreign bodies in the eye. The use of protective devices and accessibility of first aid boxes and fire extinguishers in the workplace was inadequate.

Hierbaum (Ref. 55) described an accident in which a welder was struck in the face by the metal coupling on the end of an air hose. The welder had been wearing goggles which, though they were severely mangled, spared him from eye injuries. Musa (Ref. 97) described an incident in Nigeria in which a man was welding a metal drum that exploded and hit a nearby child, severing his leg at the knee.

Effects of Welding on Human Health

Respiratory Tract

Pulmonary Function. Erhabor et al. (Ref. 36) compared the pulmonary function and general health of 44 Nigerian arc welders who worked in poorly ventilated roadside workshops with that of 50 university maintenance workers. Lung function was normal in 26% of the welders and 92% of the controls.

Occupational Asthma. Toren et al. (Ref. 150) estimated that 5% to 15% of adult-onset asthma may be caused by occupational exposures. Using data retrieved from the Finnish Registry of Occupational Diseases, Karjalainen et al. (Ref. 63) determined the incidence of occupational asthma in Finland, by occupation, industry, and causative agent, for the years 1989 through 1995. Exposure to welding fumes accounted for 8.1% of the incidence of occupational asthma in men. In a separate study, Karjalainen et al. (Ref. 64) found that welding fumes accounted for more cases of occupational asthma than any other exposures among construction workers during the years 1986 through 1998. Welding fumes were the causative agent of 8.9% of the 90 new cases of occupational asthma identified from the records of the Singapore Ministry of Manpower and through referrals to an occupational lung disease clinic between 1983 and 1999 (Ref. 69).

Keskinen et al. described the case of a 47-year-old mechanic who experienced asthmatic reactions when he used GMAW to repair heavy machinery that had been painted with a polyester paint. Clinical and laboratory tests showed that the cause of his response was the phthalic anhydride and chlorendic anhydride released from the paint during welding (Refs. 68, 110).

Pneumoconiosis. Using thin section computed tomography (CT), Han et al. (Ref. 49) examined the lungs of 85 arc welders with respiratory symptoms or abnormal chest X-rays. The extent of abnormalities observed in CT scans did not correlate significantly with deficits in pulmonary function, with the severity of dyspnea, or with the years of tobacco smoking. Takigawa et al. (Ref. 146) examined 1006 chest X-rays taken of workers in shipyard welding, stone grinding, and refractory crushing during mandatory health examinations administered over a 2-year period. Welders had the highest percent of films with abnormalities but most of these were described as pre-pneumoconiotic conditions. More advanced cases of pneumoconiosis least frequent among the welders. Buerke et al. (Ref. 21) observed interstitial pulmonary fibrosis in chest X-rays and CT scans of 15 welders from West Germany who had long durations of exposure to high levels of welding fumes in poorly ventilated workplaces. Using light microscopy, scanning electron microscopy, and energy dispersive X-ray analysis, Muller and Verhoff (Refs. 95, 152) evaluated lung tissue samples obtained by biopsy or autopsy from 43 welders. Pulmonary alterations characteristic of pneumoconiosis were seen in samples from 38 of the men. The lesions ranged from simple siderosis, with iron deposits in macrophages, to extensive interstitial fibrosis.

Yoshii et al. (Ref. 165) found that ferritin was significantly higher in bronchoalveolar lavage fluid (BALF) from welders with pneumoconiosis than it was in BALF from welders without pneumoconiosis or in that from patients with pneumoconiosis associated with silica and asbestos exposures. They concluded that measurements of ferritin in BALF may be useful for early diagnosis of welder's pneumoconiosis.

The case of a 38-year-old welder with siderosilicosis who suffered from shortness of breath and spontaneous pneumothorax was described by Strobel (Ref. 141). Two aluminum welders who died from complications of extensive aluminum pneumoconiosis were described by Hull and Abrahams (Ref. 58).

Absences Due to Respiratory Symptoms. Alexopoulos and Burdorf (Ref. 2) examined the frequency and duration of absences from work resulting from respiratory disorders among 97 welders, 125 metal workers, and 29 office clerks from two construction companies. During the 2-year follow up, respiratory complaints were responsible for 14.2% of the days off from work and 35% of the workers attributed at least one period of absence to respiratory complaints.

Respiratory Tract Infections. Aviles et al. (Ref. 8) described the case of a 52-year-old welder who died from streptococcal pneumonia. This was his fourth bout of pneumonia within a 15-year period. Mizuhashi et al. (Ref. 93) described the cases of two welders with nontuberculous mycobacterial lung infection. The Norwegian

Labor Inspection Authority issued a warning to physicians indicating that welders with pneumonia should be hospitalized because exposures to welding fumes may seriously aggravate the prognosis for this disease (Ref. 160).

Cancer

Lung Cancer. In a 10-year follow-up to a mortality study begun in the mid-1950s, Steenland (Ref. 138) found "suggestive, but non-conclusive" evidence for an excess of lung cancer among a cohort of 4459 mild steel welders who worked in four plants in the United States. In a case-referent study designed to examine the risk of lung cancer associated with occupational exposures in Sweden, Gustavvson et al. (Ref. 47) found that the relative risks for lung cancer were significantly elevated among men exposed to diesel exhaust, combustion products, and asbestos, but not among men with occupational exposures to mild steel welding fumes, metals, or oil mist. Danielsen et al. (Ref. 27) investigated the incidence of lung cancer among a cohort of 4480 workers in a Norwegian shipyard and did not find a clear relationship between exposure to welding fumes and the development of lung cancer. Non-significant increases in deaths from lung cancer were observed among welders by Puntoni et al. (Ref. 113) in a historical cohort mortality study that included 3959 workers from a shipyard in the harbor of Genoa, Italy. In a study based on medical records, Park (Ref. 106) found a significant association between welding and lung cancer when a latency period of 25 years was factored into the calculation of odds ratios.

Cancer at Other Sites. In a study by Pesch et al. (Ref. 108), long-term employment of men in the printing, chemical and rubber industries, and of women in an occupational group that included soldering, welding, and milling, was associated with an excess risk for renal cell carcinoma. Hemminki et al. (Ref. 51) found an association between exposure to welding fumes and the number and types of mutations in the von Hipple-Lindau tumor suppressor gene in renal cell carcinoma samples. In a case-control study of pancreatic cancer in Spain, Alguacil et al. (Ref. 3) observed a large but non-significantly increased risk for pancreatic cancer among men in an occupational group that included metal molders, sheet-metal workers, structural metal workers, and welders. Kaerlev et al. found that welders have a non-significantly increased risk of developing small bowel carcinoid tumor (Ref. 60) and welders and flame cutters have a statistically significant increased risk of developing small bowel adenocarcinoma (Ref. 61).

Zheng et al. (Ref. 171) analyzed data from two previously published population-based case-control studies and found that the risk of non-Hodgkin's lymphoma was significantly elevated among workers in the combined group welders and solderers. Guenel et al. (Ref. 45) investigated the role of occupational exposure to UV radiation in the development of ocular melanoma. Fishermen, sailors, and other tradesmen whose occupations were associated with excessive exposure to solar UV radiation did not have an elevated risk of developing ocular melanoma. But exposure to artificial UV was a significant risk factor, and welders and sheet metal workers had a significantly increased incidence of ocular melanoma. Currie and Monk (Ref. 25) noted that 5 of 174 male patients seen consecutively at their clinic with non-melanoma skin cancers were welders. Genetic analysis of a basal cell carcinoma excised from the skin of an 80-year-old retired welder revealed the presence of two novel mutations in the p53 gene and UV-specific mutations in the PTCH gene (Ref. 117).

Childhood Brain Tumors. Cordier et al. (Ref. 23) performed population-based case-control studies concurrently in seven countries to examine the role of parental occupations in the etiology of childhood brain tumors. No association was found between the occurrence of childhood brain tumors and paternal occupation as a welder.

Cancer Associated with Electromagnetic Fields. Bethwaite et al. (Ref. 11) conducted a case-control study of the risks of acute leukemia in workers exposed to high levels of electromagnetic fields. A significantly increased risk for leukemia with a positive exposure/response relationship was found among those who worked as electric welders/flame cutters or telephone line workers. Hakansson et al. (Ref. 48) investigated the cancer incidence in a large cohort of resistance welders and found a significantly elevated risk for cancer of the kidney among male subjects and an increase in brain tumors among female subjects. None of the subjects had an increased risk of leukemia.

Metal Fume Fever

Borak et al. (Ref. 15) searched the international literature and found insufficient evidence in humans to support an association between metal fume fever and exposure to copper fumes or dust.

Merchant and Webby (Ref. 91) described a typical case of metal fume fever in which a 26-year-old man reported to the emergency room with fever, chills, headache, muscle pain, nausea, and breathlessness 4 hours after oxygen cutting galvanized steel in a confined space without the benefit of respiratory protection. In another incident, a 55-year-old plumber, who had been disassembling a steel tank with an oxyacetylene torch, and his 18-year-old son who had been assisting him reported to the emergency room with typical signs of metal fume fever (Ref. 66). Ebran et al. (Ref. 34) described the case of a 32-year-old welder who developed metal fume fever 3 hours after exposure to zinc fumes. In this case, chest X-rays revealed bilateral diffuse infiltrative pulmonary lesions a condition which, the authors stated, is rarely associated with metal fume fever. An incident of metal fume fever was reported by Fuortes and Schenck (Ref. 41) in which a welder had a high fever, malaise, chills, muscle and joint pain, severe chest pain, a persistent productive cough and a pleural friction rub after welding galvanized steel.

Effects on the Ear

Five cases of welding spark injuries of the middle ear were described by Kupisz et al. (Ref. 74). Three of the patients had sought medical help within 2 months of their injury and showed hearing improvement within 3 months after iron filings were removed surgically. The long-lasting presence of a metal filing in the middle ear spaces of the remaining two patients led to a chronic inflammatory process with progressive hearing loss.

Effects on the Eye

Eye Injuries. A survey by Welch et al. (Ref. 159) of 3390 construction workers treated in the emergency department of a hospital in Washington, DC, over a period of 8 years, showed that welders had the highest rate of eye injuries, followed by plumbers, painters/glaziers, and insulators. A survey by Andreotti et al. (Ref. 6) showed that the incidence of ambulatory visits for eye injuries among all persons who had served in the U.S. Armed Forces during the year 1998 was three to four times higher among workers in the occupations classified as metal body repair, welding, metal working, and machinists than among the study population as a whole. In a survey of eye injuries among 646 workers in four factories in Nigeria, Okoye and Umeh (Ref. 102) found that 81 had received one or more eye injuries. "Welding arc rays" were listed among the most common sources of injury and were responsible for 12.6% of the injuries that occurred in the plants surveyed.

Visual Acuity. Boissin et al (Ref. 14) found no significant difference between the visual acuity of 850 welders and that of 281 controls who worked in twelve large companies in France. This was attributed to the protective and preventive eye care measures used by the companies that participated in the study.

Retina. Magnavita (Ref. 81) described a case of welding arc maculopathy in a 45-year-old millwright who experienced acute eye pain while welding. He developed persistent retinal lesions and a loss of visual acuity in both eyes. Mauget-Faysse et al. (Ref. 88) reported the case of a 73-year-old man who developed a central scotoma and blurred and distorted vision in his left eye after inadvertent exposure to an electric welding arc that was approximately 3 meters from the left side of his body. His use of photosensitizing drugs at the time of his exposure was a contributing factor to the development of lesions on the macula of his left eye.

Cornea. Oblak and Doughty (Ref. 100) compared photomicrographs of the corneas of 20 welders and 20 office workers. No substantial differences in the curvature or thickness of the cornea, or in the size or shape of the corneal endothelial cells, were found between the two groups.

Effects on the Skin

Using the West Virginia Workers' Compensation database, Islam et al. (Ref. 59) examined the incidence rates of work-related burn injuries that occurred during a 1-year period. They found that welders had the highest incidence rate for all burn injuries excluding those of the eye. Welders also had the highest incident rate of third degree burns.

Lack and Weingold (Refs. 76, 77) described a patient who had been referred to their dermatology practice with a painful, ulcerated wound from a welding slag burn on the back of the hand. His condition was diagnosed as a form of "Sweet's syndrome" and he experienced a rapid recovery after treatment with corticosteroids. Lichen sclerosus et atrophicus, an inflammatory skin disorder, was diagnosed by Tegner and Vrana (Ref. 147) in a 46-year-old sheet metal worker. Markandeya and Shenoi (Ref. 83) described the case of a 42-year-old welder with persistent hyperpigmentation over both forearms. Munnoch et al. (Ref. 96) used laser therapy to treat spider naevi on the cheeks of a 24-year-old welder. Despite his use of a sunscreen, the treated area became severely hyperpigmented within 6 weeks. The physicians attributed this to the high levels of UVC radiation generated by GMAW and explained that sunscreens provide protection against UVA and UVB, but not against UVC. Wagner et al. (Ref. 154) described the case of a welder who developed erythema and burning of his face after welding. Dermatologic examinations showed that he had developed photo-allergies to the two medications, hydrochlorothiazide and ramipril, he had been taking for hypertension.

Systemic Sclerosis. In a case-control study, Diot et al. (Ref. 33) observed significant associations between the development of systemic sclerosis and occupational exposures to crystalline silica, various solvents, epoxy resins, and welding fumes. Exposure to welding fumes occurred simultaneously with exposure to silica in six of the eleven subjects with systemic sclerosis, making it difficult to discern between the effects of the two exposures.

Effects on the Nervous System

Effects of Aluminum. Riihimaki et al. (Ref. 119) examined the relationship between central nervous system function and aluminum concentrations in serum and urine from 59 welders who exclusively performed GMAW of aluminum. Welders with high levels of aluminum in their urine and serum had significantly more symptoms of fatigue, emotional lability, memory loss, and difficulties in concentration, and they performed significantly less well than controls in neuropsychological test batteries. Based on these data, it was estimated that aluminum concentrations of 4 µmol/L–6 µmol/L in urine and 0.25 µmol/L–0.35 µmol/L in serum represent the threshold for multiple adverse effects in aluminum welders. Bast-Pettersen et al. (Ref. 10) examined neurobehavioral/neuromotor function in 20 aluminum welders whose mean and median urinary aluminum concentrations were 1.86 µmol/L and 1.5 µmol/L, respectively. Results of tests of tremor, reaction time, and self-reported neuropsychiatric symptoms were all within clinical standards.

Effects of Manganese. Racette et al. (Ref. 116) compared the symptoms and disease course in 15 welders with parkinsonism with those of two set of controls with idiopathic Parkinson's disease and concluded that welding may be a risk factor for parkinsonism that accelerates the progression of the disease. Frucht (Ref. 40) and Sadek and Schulz (Ref. 122) suggested that some or all of the welders in the study of Racette et al. may actually have had manganism and not idiopathic Parkinson's disease. Ravina (Ref. 118) noted that 53% of the welders in the Racette study had a family history of Parkinson's disease compared with 32% of the controls, suggesting an alternative mechanism for the early age of onset. Pezzoli et al. (Ref. 109) noted that they had found that Parkinson's disease patients who had a history of occupational exposure to hydrocarbon solvents had an earlier onset of the disease, which led them to conclude that environmental factors may accelerate the onset of Parkinsonism.

McDonnell et al. (Ref. 89) searched the national pension fund archive of death certificates and occupational records for employees from a major British automobile manufacturer to examine the association of Parkinson's disease with exposure to metals or solvents. The risk for Parkinson's disease was non-significantly elevated among those who had been exposed to solvents or metals. The risk for Parkinson's disease was not associated with the duration of exposure to metals.

Sinczuk-Walczak et al. (Refs. 133, 134) examined nervous system function in 75 manganese-exposed men (62 shipyard welders and fitters and 13 battery production workers). The manganese-exposed workers reported emotional irritability, impaired memory, difficulty concentrating, sleepiness, and paresthesia in the extremities significantly more often than did controls. Neurological examination did not reveal peripheral or central nervous system changes indicative of clinical encephalopathy or neuropathy. Tests of visual evoked potential revealed abnormalities that could be indicative of subclinical optic nerve disorders.

Ono et al. (Ref. 105) described the case of a welder who had myoclonic involuntary movements characterized by sudden brief, jerky, shock-like movements of his right arm and leg that were attributed to manganese poisoning. Chelation therapy for 5 days resulted in urinary excretion of high levels of manganese and a marked reduction in the myoclonic involuntary movements of his extremities.

Effects on the Cardiovascular System

Sjogren et al. (Ref. 135) compared mortality rates from ischemic heart disease (IHD) among male welders with that of the entire population of actively working men in Sweden. Two cohorts of welders were studied; one was followed for 5 years the second for 25 years. A small but significant increase in the mortality from IHD was observed among welders in both cohorts. The investigators determined that smoking among welders was sufficient to have caused the increased risk of IHD in the 1970 cohort but not in the 1990 cohort. Suadicani et al. (Ref. 142) conducted a study to test the hypothesis that men with type O blood are more susceptible to cardiovascular effects from occupational exposures to airborne particulate than are men with other blood types. The incidence of myocardial infarctions was significantly increased in men with type O blood who had long term exposure to fumes from soldering, welding, or plastics.

Hand-Arm Vibration Syndrome

McGeoch and Gilmour (Ref. 90) conducted a study of 74 welders, 58 fitters, 17 platers, and 16 dressers at a Scottish engineering company to examine how different trades are affected by the neurological and vascular hazards from vibrating tools. Neurological symptoms were more prevalent than vascular symptoms. Welders had the shortest latent period for hand-arm vibration syndrome of all trades examined, which was attributed to their use of pneumatic chipping hammers which have higher acceleration and cause more damage than pneumatic grinders.

Effects on the Endocrine System

In a pilot study of thyroid function, Zaidi et al. (Ref 170) compared the concentrations of the hormones thyrotropin and thyroxin (T3 and T4) in the serum of 20 welders and 20 men whose occupations had involved no welding or chemical exposures. The concentration of thyrotropin was elevated in serum from four of the welders, which caused the average concentration of thyrotropin to be significantly increased in welders compared with non-welders.

Effects on the Immune System

Aloufy et al. (Ref. 4) compared *in vitro* superoxide production by polymorphonuclear leukocytes (PMN) isolated from the peripheral blood of a group of 23 arc welders with that from 23 age- and smoking habit-matched office workers. Significantly less ($p = 0.021$) superoxide was released from stimulated PMNs taken from welders than from those taken from controls.

Ayatollahi examined serum immunoglobulin levels in 66 workers (21 battery shop workers, 12 welders of car radiators and exhausts, 21 print shop workers, and 12 car painters) with heavy exposures to lead (Ref. 9). Welders had the highest mean blood lead level among all the groups of workers. Serum concentrations of the immunoglobulins IgG and IgA were greatly reduced among all of the workers compared with population standards but there were no changes in concentrations of IgM. Borska et al. found that IgA is increased and IgM is decreased in welders (Ref. 17). Dasdag et al. (Ref. 28) compared hematologic and immunologic parameters of 16 male welders with those of 14 healthy male non-welding controls. Welders were found to have higher hematocrit levels than controls, and the number of helper T-cells and suppressor T-cells were significantly lower in the welders than in the controls.

Effects on Reproduction

Sheiner et al. (Ref. 129) found that men with male fertility problems were significantly more likely to be working in industry and construction than were controls. No significant differences were found between cases and controls when exposures to welding, noise, and other physical and chemical agents were compared. In a retrospective study of occupations associated with male infertility using data archived at their fertility clinic, Kenkel et al. (Ref. 67) found that the percentage of men in the occupational group metal workers/welders was non-significantly lower among men who were being treated in the clinic than among men in the general population. Metal workers and welders comprised the only group to show a significant decrease in sperm motility. Auger et al. (Ref. 7) conducted a multicenter study to investigate the effects of environment, life style, and occupational factors on sperm morphology among 1001 men from four European cities. Several sperm defects were significantly associated with stress, the number of hours worked per week, and with occupation as a welder. Tielemans et al. (Ref. 149) investigated whether male occupational exposures can influence the implantation of embryos in 726 couples undergoing *in vitro* fertilization. The probability of implantation was not affected by paternal exposure to metal dusts or welding fumes.

Health Surveys

In India, Prasad and Vyas (Ref. 112) compared general health of 100 welders and 41 sewing machine operators and assembly workers. Eye irritation was reported by 40% of the welders; 70% of the welders felt generally healthy compared with 80% of the controls. Liubchenko and Vinnitskaia (Ref. 79) reported that surveys of 323 electric welders in a Moscow suburb showed that the occupational disease most frequently experienced by welders was pneumoconiosis. This was followed in decreasing frequency by neurosensory deafness, chronic bronchitis, and chronic manganese poisoning.

Genotoxicity

Zhu et al. (Ref. 173) investigated whether occupational exposures in a Chinese bus manufacturing company are associated with DNA damage in lymphocytes obtained from 346 employees. DNA damage was elevated in lymphocytes from painters and mechanics but not from welders, compared with administrators. Quievryn et al. (Ref. 114) found that peripheral blood lymphocytes obtained from five stainless steel welders had 4.1 times as many DNA-protein cross links than did those from 22 controls.

Borska and Tejral et al. (Refs. 16, 148) performed a study of blood chemistry and chromosome aberrations in 11 stainless steel welders and 9 stainless steel grinders. No marked differences were found in the health status, in the complete blood count, or biochemical blood screening results between the metal workers and controls. More chromosomal aberrations were found in lymphocytes from the exposed workers than from controls.

Effects of Chromium

Perforated nasal septa were detected in eleven welders during annual health examinations of 2869 welders conducted from 1997 to 2000 in a shipyard in South Korea (Ref. 78). Breathing zone samples collected from 31 welders working in six areas where the eleven cases had been working showed mean Cr(VI) levels of 0.22 mg/m^3 with a maximum of 0.34 mg/m^3 in one of the areas, which was deemed to be sufficient to have caused their condition. Ellis et al. (Ref. 35) found no significant differences in lipid peroxidation, plasma lipid susceptibility to oxidation, or total plasma antioxidant status between 11 welders and 15 age-matched controls.

Effects of Mercury

Zlotkowska and Zajac-Nedza (Ref. 176) described a welder who experienced acute mercury poisoning after spending 3 days cutting tubes covered with mercury with an oxyacetylene torch in the acetaldehyde production area of a large chemical plant. He had symptoms of nausea, abdominal pain, headache, fever, and gingivitis. He was successfully treated by chelation.

Effects of Lead

A 57-year-old man who developed abdominal and lower back pain was hospitalized for 3 days for a diagnostic work-up and treatment for suspected kidney stones (Ref. 54). When his physicians learned that he was a welder with exposure to lead fume, he was successfully treated by chelation therapy. De Haro et al. (Ref. 29) reported that of the 45 adults with lead poisoning seen at a poison control clinic in France, 30 had been exposed to lead in the workplace. Suls (Ref. 144) also noted that the most common exposure to lead among adults is occupational, and stressed that a thorough occupational history is essential in any patient who presents with a constellation of unexplained symptoms.

Biological Monitoring

Kucera et al. (Ref. 72) measured levels of Cr, Mn, Mo, Ni, and V in samples of serum, blood, urine, hair and nails taken from 18 welders and 2 polishers of stainless steel vessels. Chromium levels were found to be significantly elevated in hair, nails, serum, and urine of the metal workers compared with controls. Molybdenum was significantly elevated in hair, and marginally significant elevations of manganese were found in whole blood samples. Luse et al. (Ref. 80) found that manganese levels were 7.6 and 3.2 times higher in blood and hair, respectively, from 46 welders than in corresponding samples from controls.

Using urinary concentrations of 1-hydroxypyrene (OHP) as a biomarker, Mukherjee et al. (Ref. 94) examined polycyclic aromatic hydrocarbon (PAH) exposure in two groups of boilermakers. The first group was exposed to mild steel welding fumes. The second group performed oxyacetylene cutting and arc welding to repair the interior wall of an oil-fired boiler. In non-smoking mild steel welders, there were no changes in OHP levels during the work shift whereas urinary OHP levels doubled during the 5-day workweek in non-smoking power plant boiler makers, reflecting their exposures to PAH in the residual oil fly ash which coated the walls of the boiler.

Investigations in Animals

Respiration

Saito et al. (Ref. 123) measured the respiratory response of rats exposed to welding fumes and gases generated by a mild steel consumable electrode. Fumes were generated by eight cycles of "bead-on-plate" welding for 6 minutes; successive cycles were separated by 9-minute pauses. The rats exhibited rapid, shallow breathing immediately after the start of the first exposure cycle which returned to normal at the end of the cycle. The intensity of the respiratory response declined thereafter, until there was no change in breathing rates by the eighth and final cycle.

Pulmonary Fibrosis

Yu et al. (Ref. 168) conducted a series of inhalation studies in rats which examined particle deposition and fibrogenic characteristics of fumes generated by SMAW of stainless steel. In the first study, rats were subjected to a single 4-hour exposure to a fume particle concentration of 62 mg/m^3 and were sacrificed 0, 1, 3, 7, 10, and 14 days later. Histopathologic examination of the respiratory tract showed that welding fume particles were concentrated primarily in the small bronchioles and alveoli. The concentration of particles began to diminish at 7 days after exposure and, by 14 days, they were almost entirely cleared from the lungs.

In the second study (Ref. 167), groups of rats were exposed for 2 hours/day for 1, 15, 30, 60, or 90 days to fume concentrations of 63.6 mg/m^3 (low dose) and 107.1 mg/m^3 (high dose). The animals in each group were sacrificed after their final exposure. Examination of respiratory tract tissues revealed little evidence of fibrosis in the low-dose rats. In the high-dose rats, there were particle-laden macrophages in alveolar spaces and signs of early fibrosis in the peribronchiolar and perivascular areas after 15 days of exposure. By 60 days, granulomatous regions, distinct fibrosis in perivascular and peribronchiolar areas, and some interstitial fibrosis were evident. In later studies, rats were exposed under the same conditions but were allowed a 90-day recovery period following the last exposure before sacrifice (Ref. 166). In high-dose rats, the fibrotic regions seen following 15-day to 30-day exposures had completely resolved and were no longer evident after the recovery period. However, the fibrotic changes seen at 60 and 90 days of exposure were not fully reversible after the 90-day recovery period.

Metal Fume Fever

Wesselkamper et al. (Ref. 161) exposed mice to 1.0 mg/m^3 ZnO for 1, 3, or 5 successive days. The number of PMNs in bronchoalveolar lavage fluid (BALF) were significantly elevated in mice 1 day after exposure but declined steadily after that. The decline in the number of PMNs reflects the probable development of tolerance to ZnO in these mice. Experiments in which mice were subjected to a single 3-hour exposure to ZnO 1 week after the first exposure showed that the tolerance was not persistent.

Effects of Welding on Health, XIII

Section One
The Exposure

1. Fume Composition

Saito et al. (Ref. 124) used an automatic welding robot to generate fumes and gases from three different consumable electrodes during gas metal arc welding (GMAW) with a carbon dioxide (CO_2) shielding gas. The electrodes tested were a solid wire for mild steel, a flux-cored wire for mild steel, and a solid wire for Cr-Mo (Cr 5%–Mo 0.5%) steel. Emissions were collected at a distance from the weld equivalent to a welder's breathing zone. There were no statistical differences in the concentrations of ozone, carbon monoxide (CO), or nitric oxide (NO) generated by the three types of electrodes. The flux-cored electrode produced the highest quantity of fumes followed in descending order by the Cr-Mo and the solid mild steel electrode. The mean aerodynamic diameter of the fume particles was approximately 0.5 µm for all of the electrodes. The respirable portion constituted 85% of the total fume and contained most of the manganese and chromium that was present in the fumes. Chromium was only detected in the fumes from the Cr-Mo electrode and its proportion in the fumes was similar to that in the electrode (see Table 1). Hexavalent chromium [Cr(VI)] represented 0.1%–0.2% of the total chromium. Manganese was found in the fumes from all three electrodes. The proportion of manganese in the fumes was approximately eightfold higher than its proportion in the consumable electrode from which it was generated. The investigators explained that the disproportionately high concentration of manganese in the fumes is due to its low boiling point.

Using a laboratory furnace to simulate workplace brazing conditions, Zimmer and Biswas (Ref. 175) compared the aerosols produced using a self-fluxing brazing alloy (89% copper, 6% silver, 5% phosphorus) with and without a supplemental fluxing compound (boric acid, potassium fluoride, and water) that is often used to prevent oxidation of the molten metal. The alloy samples were

Table 1
Percent Mn and Cr in each Electrode and its Fume, and Ratio of Mn and Cr in the Fumes and Electrodes

Electrode		Mn[a]	Cr[a]
Solid (mild steel)	Electrode	1.35%	ND
	Fume	10.4%	ND
	Ratio of Fume/Electrode	7.7	
Flux-cored wire	Electrode	2.19%	ND
	Fume	18.9%	ND
	Ratio of Fume/Electrode	8.6	
Solid (Cr-Mo)	Electrode	0.46%	4.98%
	Fume	3.62%	5.56%
	Ratio of Fume/Electrode	7.9	1.1

[a] The values are arithmetic means of ten welding operations for each electrode; ND = not detected.
Source: Data from Saito, Ref. 124.

placed in a 1-inch alumina tube flow reactor inserted into the furnace. Particle-free air or nitrogen was used as the carrier gas, and temperatures were varied between 700°C and 1000°C. An electrostatic sampler was used to collect aerosol samples for elemental analysis, and an electron capture particle size detector was placed at the exit of the tube.

When the tests were performed in the absence of the supplemental fluxing compound, the aerosols formed were transient and were composed of phosphorus compounds. When the fluxing compound was added, a much more stable aerosol, composed of submicron particles, was generated. The concentration of fumes was magnitudes higher with the fluxing compound than with the alloy alone. Results of thermodynamic modeling of the equilibrium among the species present in the aerosols indicated that the aerosols produced in the presence of the supplemental fluxing compound consisted mainly of metal fluoride compounds, which are more volatile than the metal oxides or the elemental metals. The analysis also showed the potential for formation of the severe pulmonary irritants, hydrogen fluoride and bromine trifluoride. These findings led the authors to conclude that occupational exposures to aerosol from brazing are minimized by the use of self-fluxing alloys without supplemental fluxing compound.

In later work, Zimmer (Ref. 174) analyzed electron micrographs of aerosols from GMAW and flux cored arc welding (FCAW) in addition to those from the brazing experiment. Submicron particles were seen in all samples. Those from Ar-CO_2 shielded GMAW of a 97%–98% iron alloy were homogeneous chain-like aggregates. The aerosols produced from FCAW were heterogeneous, consisting of chain-like and spherical structures, and those generated by brazing were predominantly spherical. Zimmer postulated that, after being inhaled into the lungs, the weakly-bound chains from GMAW could de-agglomerate within the pulmonary surfactant, resulting in a large number of ultrafine particles with diameters of 0.01 micron (μm) or less. He noted that ultrafine particles may be more toxic than larger particles, in part, because they may pass more readily through the pulmonary interstitium.

In 1995, Dennis and Mortazavi (Ref. 32) reported that ozone emission during GMAW could be substantially reduced by using a modified welding gun that produced two concentric argon gas shrouds, with the internal shield containing 5% CO_2 and the outer shield containing 300 ppm nitric oxide. More recently, these investigators examined the effect of altering the additives in the outer shield gas on the concentration of Cr(VI) in the fumes (Ref. 31). The primary (internal) shielding gas used throughout this work was Argoshield 5 (Ar + 5% CO_2 + 2% O_2) and the three secondary shielding gases tested were neat argon, Mison (Argon + 0.03% NO), and argon containing 0.3% ethylene. The Cr(VI) and ozone levels in fumes generated with these secondary shielding gases were compared with those measured when the four shielding gases were used as a single shroud with a conventional GMAW gun. The ethylene and nitric oxide in these gases function by reducing ozone (O_3) to oxygen (O_2) in the vicinity of the arc.

Table 2 shows the effects of the three outer shielding gases on the concentrations of ozone and Cr(VI) gener-

Table 2
Effect of Additives in Shielding Gas on Levels of Cr(VI) and Ozone in Fumes Generated by GMAW of Stainless Steel

Conventional Torch (Single Shroud)			Modified Torch (Double Shroud)			
Shielding Gas	Ozone (ppm)	Cr(Iv) %	Primary Shielding Gas	Secondary Shielding Gas	Ozone (ppm)	Cr(IV) %
Argon	1.32	0.61	Argoshield 5	Argon	1.1	0.64
Argoshield 5	0.95	0.57	Argoshield 5	None	0.83	0.58
Mison (Ar + NO)	0.39	0.18	Argoshield 5	Mison (Ar + NO)	0.05	0.35
Argon + ethylene	0.69	0.38	Argoshield 5	Argon + ethylene	0.11	0.37

Shielding gases: Argoshield 5 = (Ar + 5% CO_2 + 2% O_2); Mison = (Argon + 0.03% NO), Argon + ethylene = (argon + 0.3% ethylene).
Source: Data from Dennis et al., Ref. 31.

ated by welding with a stainless steel electrode. While the use of an outer shield containing nitric oxide (Mison) or ethylene caused a greater than 90% reduction in ozone levels compared with an outer shield of argon with no additives, the effects on Cr(VI) were less impressive. Nitric oxide or ethylene in the outer shield caused only a 40% reduction in Cr(VI) which is similar to that obtained with a single shield of argon with ethylene and higher than that observed with a single Mison shield. Thus, while an outer shield of argon containing nitric oxide or ethylene can substantially reduce ozone levels, these outer shields are not effective in reducing Cr(VI) and, in the case of Mison, may increase the concentration of Cr(IV) beyond that which can be achieved with a single shield of Mison alone. The investigators noted that their results are based on mass percent of Cr(VI) in total fumes and suggested that the Cr(VI) formation rate (mass per unit time) should be evaluated in future work.

In a companion study, Dennis et al. (Ref. 30) showed that replacing potassium with lithium in a self-shielding flux cored electrode reduced the fume formation rate and levels of Cr(VI) in fumes. This work also showed that incorporation of zinc into an experimental Cr-containing self-shielding flux cored electrode reduced the concentration of ozone produced, provided that the shielding gas contained no oxygen. A metal cored electrode with a mild steel sheath and a core containing Cr and different levels of zinc were used. With one or two percent oxygen in an argon shielding gas, the amount of ozone produced from an electrode containing 1% zinc was twice that produced from an electrode containing no zinc.

2. Analytical Procedures

2.1 Chromium. Scancar, Milacic, and Tusek (Refs. 92, 125) explored two chromatographic procedures for quantification of Cr(VI) in welding fumes. Both procedures were validated using standard reference welding dusts containing known quantities of Cr(VI) and were found to be highly reproducible (±3.0%). The first procedure (Ref. 92) used anion-exchange fast protein liquid chromatography (FPLC) with electrothermal atomic absorption spectrometry (ETAAS). To field test the system, fumes generated by gas tungsten arc welding (GTAW) of stainless steel were collected on polycarbonate membrane filters (pore sizes: 8 μm and 0.4 μm) housed in a sampling chamber with two successive filters which captured particles in the inhalable and respirable size range. Chromium was leached from the filters with alkali using standard procedures. The concentrations of total chromium and Cr(VI) were determined by ETAAS and anion-exchange FPLC-ETAAS, respectively. More than 80% of the total chromium was present in the very fine particulate fraction (<0.4 μm). Hexavalent chromium represented 91%–96% of the total chromium in the very fine particulate fraction (<0.4 μm) and 50%–75% of the total chromium content of the larger particles (<8 μm).

The second procedure (Ref. 125) examined the utility of convective-interaction media fast-monolithic chromatography (CIM) with ETAAS as the detection system for determination of Cr(VI). Samples collected during plasma arc cutting (PAC) of stainless steel (18% Cr, 8% Ni) were examined using this procedure. The Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for Cr(VI) of 0.5 μg/m^3 was exceeded in most of the personal fume samples collected. In contrast to the results obtained with GTAW of stainless steel, the concentrations of total chromium and Cr(VI) were higher in the coarser fraction than in the very fine particulate fraction generated by PAC. In both GTAW and PAC, Cr(VI) represented a greater percentage of the total chromium in the very fine particles than in the coarser particles. Analysis of the PAC samples was repeated by FPLC and the results of the two procedures were statistically indistinguishable. Overall, the accuracy and reproducibility of CIM were equivalent to that of FPLC. The major advantage of the CIM procedure was that it was twice as fast as FPLC.

2.2 Thorium. Holmes and Pilvio (Ref. 57) reviewed published analytical methods for the radioactive element thorium (^{232}Th), and concluded that techniques such as gamma spectroscopy, neutron activation analysis, and inductively coupled plasma atomic emission spectrometry-atomic emission spectrometry were not ideally suited for measurement of thorium in environmental and workplace samples. They conducted experiments applying inductively coupled plasma mass spectrometry (ICP-MS) to environmental reference materials (soils, sandstone, and lake and river sediments). The detection limit for thorium was 5 to 50 picograms/ml (pg/ml). The sample matrix was made with 5% nitric acid to counteract the "memory effect" caused by the tendency of thorium to adhere to surfaces of containers and instruments. Bismuth was used as an internal standard for thorium and was found to be suitable for that purpose. The authors concluded that ICP-MS is a powerful technique for detection and measurement of natural thorium. The application of ICP-MS to determination of thorium in tungsten welding electrodes is to be part of a future study.

3. Electromagnetic Radiation

3.1 Blue Light. Exposure to intense blue light in the visible range of 400 to 500 nanometers (nm) can cause photoretinitis which, upon examination of the eye, appears as edema, white spots, or holes in the retina. Symptoms of photoretinitis appear within 24 hours after exposure and may include decreased visual acuity, blurred vision, and scotoma (blind spot). The symptoms usually disappear gradually within weeks or months, but may not resolve in some cases. Okuno et al. (Ref. 104) examined the blue-light hazard associated with GMAW, shielded metal arc welding (SMAW), plasma arc cutting, several industrial light sources, and the sun. The blue-light effective radiance was determined and permissible daily exposures calculated for each process in accordance with American Conference of Governmental Industrial Hygienists (ACGIH) guidelines. Tests with SMAW and CO_2-shielded GMAW were conducted under laboratory conditions. GMAW was tested at eight welding currents ranging from 120 to 400 amperes (A) and SMAW was tested with two different electrodes, each at two different currents. The blue-light effective radiance associated with plasma arc cutting was measured in the workplace.

The effective radiance increased with the welding current for both GMAW and SMAW. CO_2-shielded GMAW had the highest effective radiance of the arc welding and cutting procedures examined. The permissible daily exposure time for this process at different welding currents ranged from 0.63 to 2.7 seconds and overlapped with that measured for the sun. The effective radiances measured for SMAW were slightly lower than those for GMAW, and the permissible daily exposures ranged from 2.9 to 5.3 seconds. While plasma arc cutting was less hazardous than GMAW and SMAW, it still had a high effective radiance with a permissible exposure time of 10 seconds. Thus, the arc welding and cutting processes examined are capable of producing photoretinitis with short exposures and are considered to be very hazardous to the retina.

3.2 Ultraviolet Light. Acute effects of exposure to ultraviolet (UV) light include erythema (reddening of the skin) and photokeratitis (welder's flash or arc eye). The symptoms of photokeratitis, a common injury among welders, include ocular pain, photophobia (abnormal sensitivity to light), and a sensation of sand in the eyes. Using a welding robot under laboratory conditions, Okuno et al. (Ref. 103) measured the effective radiance for UV light generated by CO_2-shielded FCAW and GMAW. Permissible exposure times were calculated from the effective radiance in accordance with the ACGIH standard.

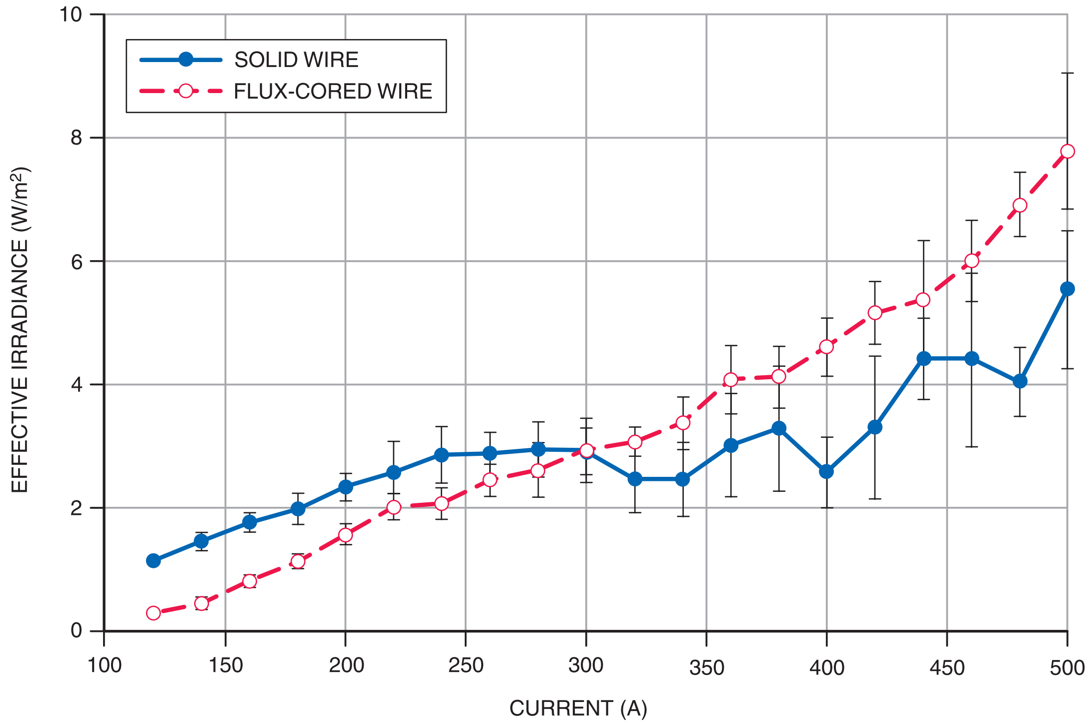
Tests were conducted with solid and flux-cored wires at eight welding currents between 100 A and 500 A. The effective radiance was measured at distances of 25 cm to 165 cm from the arc and at angles of 0° to 70° from the base plate. The results obtained for the solid and flux cored wires were similar and the effective radiance tended to increase with the welding current for both (see Figure 1). The effective radiance was found to be inversely proportional to the square of the distance from the arc, as expected based on the inverse square law, and varied with the angle, reaching a maximum at about 50° to 60° from the plate surface. At this angle, the most intense UV radiation would be directed to the face when the worker assumes a typical welding position. At a distance of 1 meter from the arc, the permissible exposure time varied from 4 to 100 seconds depending on the welding current, indicating that the welding procedures studied present a radiation hazard to the eyes and skin. Since welders are generally closer than 1 meter to the weld, the permissible exposure time would be even lower than this and the exposures that would be received by the unprotected eye would be higher. Okuno et al. also noted that UV radiation may present a hazard to nearby workers since, at a distance of 10 meters from the arc, the permissible exposure time measured under different test conditions ranged from 6 minutes to 3 hours.

In a similar study, Kozlowski (Ref. 71) determined effective radiances and safe exposure times for welding processes based on Polish Threshold Limit Values. For these studies, welding was conducted at currents that ranged from 40 A to 60 A, and measurements were taken at 0.75 meters from the arc. A safe exposure time of 3 seconds was determined for daily exposures to argon-shielded GMAW. For SMAW, the safe exposure times ranged from 2.3 to 7.2 seconds for three different electrodes. For oxyfuel gas welding and cutting, the respective safe exposure times were 2.5 hours and 1.43 hours, reflecting the much lower blue-light hazards associated with these processes.

4. Incidental Exposures

4.1 Lead. The California Occupational Safety and Health Administration (Cal/OSHA) Construction Safety Order requires that "all surfaces covered with toxic preservatives, including coatings which generate toxic substances upon heating, shall be stripped for a distance of at least four inches from the area of heat application." If this is not done, workers must wear supplied air respirators. Federal OSHA regulations are similar but apply to the welding or cutting of lead-coated surfaces in confined spaces only.

In response to reports received by the California Department of Health Services that ironworkers cutting steel



Source: Okuno et al., Ref. 103.

Figure 1—Changes in Effective Radiance (Mean ± Standard Deviation) for Ultraviolet Radiation at 1 meter from the Arc with Welding Current

that had been cleansed to the required specifications may, nonetheless, be exposed to high airborne lead levels, Brumis et al. (Ref. 20) measured lead exposures of a worker who was cutting steel on a bridge that had been originally coated with paint that contained 4.2% lead. No lead was detected in areas that had been stripped prior to cutting, demonstrating that the paint had been successfully removed by sand blasting. Breathing zone air samples were collected within the welding helmet for two consecutive days. The worker's 8-hour time-weighted average (TWA) lead exposure was determined to be approximately 4000 μg/m^3 (80 times higher than the OSHA PEL of 50 μg/m^3). The investigators attributed the high lead exposure to improper preparation of the steel surface before cutting. In some cases, the steel was stripped to only 1.25 inches from the area to be cut, despite the required 4 inch stripped area. In some places that were difficult to reach, the lead-based paint was not removed at all from the steel. Cutting of unstripped steel created much higher lead exposures than did cutting of inadequately stripped steel, but all of the measurements exceeded the PEL.

4.2 Phosgene. Chlorinated hydrocarbons, such as trichloroethylene, 1,1,1-trichloroethane, and trichloroethylene, are frequently used as degreasing agents or solvents. These compounds can present a hazard in welding shops because they can react with UV radiation, producing highly toxic compounds such as phosgene and dichloroacetyl chloride, which can cause severe acute respiratory tract irritation and pulmonary edema (accumulation of fluid in the lungs). Several incidents in which workers suffered severe respiratory tract irritation thought to be due to exposure to decomposition products of chlorinated hydrocarbons while welding in areas where degreasing agents were used have been described in the past (Refs. 121, 127, 136). In these incidents, the affected welders were using GMAW or GTAW to weld steel that had been degreased with trichloroethylene and/or 1,1,1-trichloroethane. Because there is generally a lag period between exposure to phosgene and onset of symptoms, and workplace ambient air conditions are often difficult to reconstruct, the presence of decomposition products during such incidents is generally difficult to document.

Nieuwenhuizen and Groeneveld (Ref. 99) measured the concentrations of phosgene formed when welding was conducted in an enclosed laboratory chamber containing known concentrations of vapors of each of four chlorinated hydrocarbons (trichloroethylene, carbon tetrachloride, chlorodifluoromethane, and dichloromethane). Welding took place for 1 minute, during which time 60% of one electrode was consumed. Air samples were withdrawn from the chamber for 20 minutes after the start of welding and the concentration of phosgene determined.

Phosgene was produced during welding in the presence of each of the chlorinated hydrocarbons. Trichloroethylene was associated with, by far, the highest phosgene concentration. Carbon tetrachloride produced the next highest phosgene concentration, followed by chlorodifluoromethane and dichloromethane. From their data, the investigators estimated that during the use of one electrode for a 1 minute period in the workplace, the short-term Maximum Allowable Concentration (MAC) of 0.1 ppm (equivalent to the TLV of 0.1 ppm) for phosgene would not be attained at air concentrations of dichloromethane or carbon tetrachloride equivalent to their MAC values. However, the short-term MAC value for phosgene would be attained at concentrations much lower than the MAC values for trichloroethylene and chlorodifluoromethane. Thus, they concluded that the concentration of trichloroethylene or chlorodifluoromethane must be much lower than their respective MACs to ensure that hazardous concentrations of phosgene are not formed during welding. In this work, the investigators described the welding process used in their tests as “roughly” a SMAW process, with modifications as necessitated by the experimental limitations. They stated that the quantity of phosgene measured was low because of its interactions with smoke particles, making it difficult to translate their laboratory results to the workplace. In addition, it should be noted that gas-shielded welding processes generate more UV radiation than does SMAW, and would be expected to produce proportionately more phosgene from chlorinated hydrocarbons than SMAW. Thus, the results obtained in this work may understate the risks that would exist during gas-shielded welding in the presence of chlorinated hydrocarbons.

4.3 Isocyanates. Isocyanates are highly reactive compounds used in the manufacture of polyurethane products such as foams, coatings, paints, and adhesives. The isocyanates are strong irritants of the skin, mucous membranes, and the respiratory tract. Methylene diphenyl diisocyanate (MDI), hexamethylene diisocyanate (HDI), and toluene diisocyanate (TDI) are among the most commonly used isocyanates. They are strong sensitizers (allergens) and have been linked with occupational asthma (Refs. 69, 150). Exposures to isocyanates may occur during welding and other processes that cause the thermal degradation of polyurethane products. Air sampling strategies for the determination of airborne isocyanates and related compounds formed during the thermal degradation of polyurethane in workplace environments were evaluated by Karlsson et al. in Sweden (Refs. 64, 65) and Henriks-Eckerman et al. in Finland (Ref. 53). Henriks-Eckerman et al. (Ref. 52) examined breathing zone samples collected for 3 to 30 minutes during grinding and welding operations in two car repair shops and during welding and cutting of MDI-based polyurethane-insulated district heating pipes as they were being installed (Ref. 52).

The isocyanates most frequently detected in car repair shops during grinding and GMAW were MDI, TDI, and HDI. Gas metal arc welding of metal coated with polyurethane paints was the major source of TDI in the car repair shops. The MDI was present in patching compounds used for repairing bumpers and was released through grinding operations. The thermal degradation products isocyanic acid and methyl isocyanate were detected only during welding. MDI was the main thermal degradation product found during oxyacetylene welding and cutting of district heating pipes A pattern of airborne isocyanates similar to that detected by Henriks-Eckerman et al. was also observed by Karlsson in similar working environments in Sweden (Ref. 64).

Breathing zone concentrations of isocyanates were less than 35 $\mu g/m^3$, the Finnish short-term (15 minute) Occupational Exposure Limit (OEL) for di- and triisocyanates. Henriks-Eckerman et al. noted that short exposure peaks above the OEL were possible and could have been missed during the sampling periods. Exposure to airborne diisocyanates was also assessed by measuring isocyanate-derived amines in acid-hydrolyzed urine samples collected from workers who participated in the air sampling studies (Ref. 120). The personal exposure measurements were supported by the biomonitoring results which identified exposure to MDI and TDI in car repair workers and MDI among pipe layers. Concentrations of TDI, measured as toluenediamine, and MDI, measured as methylenedianiline, were 2 to 4 times higher in urine from car repair workers than in that from the unexposed office workers who served as controls. Welders of district heating pipes insulated with MDI-based polyurethane had urinary methylenedianiline levels about 30 times higher than did controls.

5. Workplace Exposures

Tests conducted under laboratory conditions have demonstrated that pulsed arc GMAW produces less fume than conventional GMAW. To determine whether this holds true in the workplace, Wallace et al. (Ref. 156) compared exposures to pulsed arc and conventional GMAW at an agricultural and construction equipment manufacturer. Low carbon steel was the primary metal welded, and the power supplies could be used for either pulsed or conventional GMAW. Local exhaust ventilation was not used. Total welding fume samples were collected from the breathing zones of 29 welders during three consecutive 10-hour shifts. On the first day of sampling, approximately half the welders used conventional GMAW and the remainder used pulsed GMAW. The welders switched to the other welding technique on the second day and most returned to the technique they originally used on the third and final day of sampling.

The ACGIH Threshold Limit Value (TLV) for welding fumes (5 mg/m^3) was exceeded in 12% of the samples collected during conventional welding compared with 3% of the pulsed welding samples. Overall, the use of pulsed arc GMAW led to a statistically significant 24% reduction in welding fume concentrations. A multiple comparison test performed on several elements (Al, Ba, Cr, Cu, Fe, Mg, and Zn) indicated that exposures generated by pulsed GMAW were significantly[1] lower ($p < 0.01$) than those generated by conventional GMAW. However, the manganese concentrations in the fumes generated by the two techniques did not differ. Airborne manganese ranged from 0.05 mg/m^3 to 0.60 mg/m^3 and, for both conventional and pulsed GMAW, almost half of the full-shift manganese exposures were greater than the manganese TLV of 0.2 mg/m^3.

Pulsed arc welders were exposed to levels of ozone 40% higher than were conventional welders, but the results were not statistically significant due to the large variability in the data. The investigators explained that although the average arc energy of pulsed GMAW is lower than that of conventional GMAW which leads to lower fume emissions, the peak amperage is higher which leads to higher UV radiation. The increased UV radiation in turn increases ozone levels. The investigators concluded that replacement of conventional GMAW with pulsed arc techniques can reduce welders' exposures to fumes.

A National Institute for Occupational Safety and Health (NIOSH) survey described by Mattorano et al. (Ref. 87) measured exposures to toxic metals during demolition, scrapping, and dismantling of ships. Thirty-six personal samples were collected from the ten shipyard workers involved with welding, grinding, or oxypropane cutting. Breathing zone concentrations of the metals examined varied with the region of the shipyard in which they worked and the tasks they performed.

Two workers performed SMAW and GMAW under a barge in dry dock. None of the metals measured in this area exceeded regulatory limits. Three workers used SMAW to install new materials inside barge tanks. The TLV for manganese was exceeded by more than eight-fold and that for lead was exceeded by about seven-fold in some personal samples collected during this process. The barge tanks were confined spaces, with a 2-foot-diameter open portal on one end through which the welders entered. Dilution ventilation was achieved by blowing air into the tank through flexible ductwork, which was placed in the tank via the access portal used by the workers. Mattorano et al. noted that local exhaust ventilation would have been much more effective in reducing exposures than the dilution ventilation in use at the time of the survey. In addition, they noted that wet and muddy floors, inadequate lighting, and large structural support beams within the tanks added to the hazards of working in these areas.

Exposures were highest during oxypropane cutting, which was being used to remove nonferrous metal from the engine room of a ship and to cut scrap metal. TLVs and PELs for lead, cadmium, and copper were all exceeded in 8-hour time-weighted-average samples collected during these processes. Breathing zone concentrations of lead and cadmium were found to be as high as eight and ten times their PELs. The metals identified in the breathing zone samples were also found in paint chips removed from the metal structures being cut. The paint chips from one area contained up to 9.5% lead.

All of the welders and cutters wore NIOSH-approved, half-face, air-purifying respirators equipped with organic vapor and HEPA filters, which in most cases were sufficient to keep personal exposures below occupational exposure limits. These respirators had been assigned "protection factors" of 10 by NIOSH which means that the total exposure to any one metal must be less than ten times its PEL. Concentrations of cadmium exceeded 10 times the PEL in personal samples collected from two workers performing oxypropane cutting. The respirators,

[1] Throughout this volume, "significance" or "significant" refers to statistical significance. If associations are non-significant, they may have occurred by chance.

therefore, did not meet the NIOSH criteria for protection of these workers from overexposure to cadmium.

Korczynski assessed the levels of noise, fumes, ozone and carbon monoxide in eight welding companies in Manitoba, Canada (Ref. 70). GMAW of mild steel represented 90% of the welding at these plants. The remainder was GMAW of stainless steel and GTAW of aluminum. Personal exposures to noise measured for 44 of the 124 welders employed at these companies ranged from 79 dB(A)–98 dB(A) and the mean, 89 dB(A), was in excess of the 80 dB(A) action level standard for an 8-hour day in Manitoba. Sources of noise other than welding were metal fabrication (grinding, shearing, and forming of metal) and plasma arc cutting.

Personal exposures to welding fumes and gases were determined for 42 of the welders. Iron and manganese were the major metals identified in fumes from GMAW of mild steel. Personal exposures to manganese ranged from 0.01 mg/m^3 to 4.93 mg/m^3 and exposures to iron ranged from 0.04 mg/m^3 to 16.29 mg/m^3. Sixty-two percent of the welders had exposures to manganese greater than the TLV of 0.2 mg/m^3 and 19% had exposures to iron greater than its TLV of 5.0 mg/m^3. The highest manganese and iron exposures were seen in two welders who worked in enclosed areas with only natural or general ventilation. Ozone was not detectable in the breathing zones of the welders and only trace levels of carbon monoxide were detected.

Woskie et al. (Ref. 163) examined exposures to dust, quartz, diesel exhaust, and welding fumes among workers involved in the Boston Central Artery/Tunnel Project. Welding fume exposures occurred primarily in partially enclosed environments during excavation support operations when steel cross beams were welded in place. Twenty-two personal welding fume samples were collected during SMAW of mild steel. Welding fume concentrations equaled or exceeded the TLV of 5 mg/m^3 in 17 of the 22 samples. Fluoride concentrations exceeded the TLV (2.5 mg/m^3) in two samples and three samples had manganese concentrations equivalent to the TLV (0.2 mg/m^3). The concentrations of the other elements measured (Zn, Fe, Cu, Ti, Ca, Al, Si, Sb, Mg, Na, and K) were all below their respective TLVs.

In a series of studies conducted in Poland, Matczak and Gromiec measured exposures to aluminum, copper, and gases produced by welding aluminum, copper, and steel, respectively (Refs. 84, 85, 86). In the first study (Ref. 84), breathing zone samples were collected from 46 workers engaged in GMAW of an Al/Mg/Mn alloy in two plants and from 18 workers engaged in GTAW of aluminum in a third plant. During GMAW, the mean breathing zone fume concentrations were 8.8 mg/m^3 and 5.0 mg/m^3 in each of the first two plants, while the mean breathing zone fume concentration associated with GTAW fumes was much lower (0.17 mg/m^3). The Polish MAC for aluminum (2 mg/m^3) was exceeded in more than half of the GMAW samples. The authors noted that the elemental composition of the fume samples and their respirable fractions differed considerably depending on the welding method, the nature of the welding operations, and the work environment.

The next study assessed exposure of copper welders to total fumes and to soluble and insoluble copper generated by SMAW and plasma arc welding (Ref. 86). Mean breathing zone concentrations measured were 3.1 mg/m^3 (range: 0.7 mg/m^3–7.6 mg/m^3) for fumes, 0.08 mg/m^3 (range: 0.02 mg/m^3–0.17 mg/m^3) for soluble copper, and 0.4 mg/m^3 (range: 0.08 mg/m^3–0.76 mg/m^3) for insoluble copper. Copper represented 17% (range: 9.5%–28.5%) of the fume samples and, on average, copper levels in breathing zone samples exceeded the Polish MAC.

In the final survey, Matczak and Gromiec (Ref. 85) evaluated exposures of welders of mild and stainless steel to the gases Nox, CO, CO_2, and O_3. The welders were employed in shipyards and other metal product fabrication plants where they used a variety of techniques including SMAW, GMAW, GTAW, laser cutting, oxy-fuel gas, plasma arc, and resistance welding. Time-weighted average and short-term concentrations of gases were determined in both personal and area air samples. The TWA concentrations for all gases were below their respective MACs but some excursions above short-term exposure limits were seen.

Kucera et al. (Ref. 73) examined workplace exposures of 18 males and 2 females who worked at a plant in the Czech Republic that manufactured vessels for the pharmaceutical, food, and chemical industries. The male participants were involved with welding, polishing, drilling, and assembling of stainless steel constructions while the two female participants were only involved with polishing the vessels. The vessels were composed of austentitic stainless steel containing 18% Cr, 9%–10% Ni, 2%–2.5% Mo, 1%–2% Mn, and traces of V. SMAW was the primary welding procedure used. Personal samples were collected from each participant through two full work shifts.

The participants were grouped according to the activity in which they were engaged during the sampling periods. The median breathing zone concentration of chromium exceeded the Maximum Admissible Limit (MAL) of 50 μg/m^3 for 67% of the welders and 44% of the polishers. The MAL for nickel was exceeded in breathing zone samples from 33% of the polishers but from none of the other workers. None of the workers experienced exposures in excess of the MAL for Fe, Mn (MAL = 2 mg/m^3), Mo (MAL = 5 mg/m^3), or V (MAL = 1 mg/m^3).

Susi et al. (Ref. 145) evaluated aerosol exposures of construction workers using welding and thermal cutting techniques at nine construction sites located throughout the U.S.A. Over a 2-year period, 195 personal samples were collected from 63 persons who worked as pipefitters, ironworkers, or boilermakers. Samples were collected for at least 7 hours of an 8-hour work shift. All samples were analyzed for total particulate, and some were analyzed for Ni, Cr, or Cr(VI) during welding of stainless steel or for Mn during welding of mild or carbon steel.

Table 3 summarizes the mean exposure measurements for total particulate and for Cr, Mn, Ni, and Cr(VI). In all cases, the means were equal to or less than the TLV. When the data were examined by trade, the exposure to total particulate was highest for boilermakers followed in descending order by ironworkers and pipefitters. The mean concentration of manganese in all samples was less than the TLV, but the TLV was exceeded in 72% of the samples from the boilermakers, 15% of those from the ironworkers, and 7% of those from the pipefitters. When local exhaust was used, exposures were frequently higher during outdoor welding than during indoor welding. This was thought to be due, in part, to reduction of the effectiveness of local exhaust ventilation by ambient air movement during outdoor work. During indoor work, mechanical and local exhaust ventilation were about equally effective and both were significantly more effective than natural ventilation. Some of the highest exposures were seen when several welders were working together in an enclosed vessel, even though mechanical ventilation was used.

Smargiassi et al. (Ref. 137) examined manganese exposures during welding operations in a factory in Quebec where accessories for heavy excavation machinery were assembled. Each welding station was equipped with a flexible-arm local exhaust and the welding guns all had integrated exhaust systems. Total manganese (MnT) and respirable manganese (MnR, particle size cutoff: 4 µm) were determined in breathing zone samples collected for two or three full shifts on consecutive days from ten welders engaged in GMAW of mild and carbon steel parts using a flux-cored electrode containing 1%–5% Mn. The participants were divided into two groups according to whether they welded large or small parts (small parts were defined as those being welded on tables during sub-assembly).

Concentrations of manganese varied substantially with the size of the part being welded. The TLV for manganese of 0.2 mg/m^3 was exceeded in 78% of the total manganese samples collected during the assembly of large parts but in none of the samples collected during the assembly of small pieces. Nearly 90% of the manganese in the samples collected during welding of small parts was present in the respirable fraction while about 60% of that collected during welding large parts was respirable. For the small parts, the geometric means (GM) of the levels of MnT (GM: 0.059 mg/m^3) and MnR (GM: 0.052 mg/m^3) were both well below the TLV for manganese. For the large pieces, the geometric mean of the MnT (GM: 0.24 mg/m^3, n = 14) but not the MnR (GM: 0.14 mg/m^3, n = 12) exceeded the TLV.

The investigators attributed the significantly higher manganese exposures that occurred when welding large pieces to the semi-enclosed environment represented by the large buckets and scoops worked on in this factory

Table 3
Mean Exposures Relative to ACGIH Threshold Limit Values (TLVs)

Analyte	Number of Samples	Mean (mg/m^3)	TLV (mg/m^3)
Total particulate	195	5.00	5
Chromium	24	0.08	0.5
Cr(VI)	9	0.006	0.01
Manganese	136	0.13	0.2
Nickel	27	0.05	Elemental: 1.5 Soluble: 0.1 Insoluble: 0.2

Source: Data from Susi et al., Ref. 145.

and to the awkward postures that welders had to assume when working on them. They noted that the exhaust systems integrated into the GMAW equipment used in this factory efficiently reduced dust and fume exposures only when the welder and the gun were properly positioned. Optimal fume collection occurs when the gun is positioned at 90° ± 15° with respect to the welding plane and when welders remain upright, keeping the welding plume out of their breathing zones. In semi-enclosed environments, positioning the gun correctly for effective exhaust is more difficult, and the welders of large parts were not always able to follow these guidelines due to the postural and physical constraints imposed by these large pieces.

6. Hygiene and Work Practices

6.1 Ventilation. Reduction in welding fume exposures can be achieved by use of welding processes that produce less fume (Ref. 157) or by the proper use of ventilation, especially in confined spaces or areas with minimal natural air flow. Wurzelbacher et al. (Ref. 164) compared the effectiveness of dilution ventilation with that of local exhaust ventilation (LEV) during welding in confined spaces in a shipyard. The welding was performed by three volunteers in barge hull assemblies that were typically 2 feet high, 2 feet wide, 16 feet long, and open on one end. Dilution ventilation was accomplished by forcing air into the hull cell from the open end using an electric fan. An 8-inch circular opening in the closed end of the cell allowed air to exhaust into the adjoining cell. The fans were rated at 980 cubic feet per minute (cfm) in free air, but on-site readings showed that they produced a flow rate of 193 cfm (3 air changes per minute) through the cell. Local exhaust ventilation was produced by placing an air horn in the opening at the forward end of the cell to draw air through it. This arrangement produced a flow rate of 977 cfm (15 air changes per minute) through the cell.

Total particulate was collected with personal air samplers placed on the lapels of the welders during the entire time they worked in the cell. The reduction of total particulate was about 75% greater with LEV than with dilution ventilation. These results were in accord with findings that the flow rate in the hull cell was about five times greater with the LEV than with the dilution ventilation configuration. The authors concluded that breathing zone air quality would be improved by the consistent use of LEV. Additional reduction in exposure could be achieved by having welders start the weld near the exhaust port and work their way backwards toward the open end, so that fresh air is drawn through and welding fumes are drawn away from the breathing zone.

Ojima et al. (Ref. 101) used a welding robot in an enclosed chamber to study the effects of air duct ventilation on breathing zone exposures to welding fumes and gases during GMAW of rolled steel with a carbon dioxide shielding gas. The laboratory conditions were designed to mimic the exposures encountered by welders in shipyards and in the bridge building industry, where welding is often carried out inside structural components with insufficient space for installation of conventional exhaust hoods. The chamber was an aluminum cube with 1.4-meter sides. An external blower connected to a PVC air duct inserted into the chamber 85 cm above the work bench provided exhaust ventilation at a rate of 1.08 cubic meters per minute to 1.80 cubic meters per minute (0.40 air changes per minute to 0.67 air changes per minute). Air temperature and the concentrations of welding fume, ozone, and carbon monoxide were measured 60 cm above the weld, a point that would be in the breathing zone of a human welder. Studies were conducted with and without ventilation, and at welding currents that varied between 120 A and 300 A. Arc time for each experiment was 6 minutes. Air monitoring in the chamber began when the arc was struck and continued for 24 minutes after the arc was turned off.

The air temperature was found to increase with the welding current. With the blower turned off, the temperature rose to a maximum at 8 minutes after the arc was struck and then declined gradually thereafter. The maximum rise in air temperature was 14°C with a welding current of 300 A. The investigators noted that temperature rises of this magnitude might be sufficient to cause heat stress if multiple welding operations were carried out under these conditions. Concentrations of fumes, ozone, and carbon monoxide peaked during the first 30 seconds of welding and did not appear to correlate with the welding current. Ozone concentrations were reduced from 0.22 ppm during the 6-minute welding operation to just below the OSHA PEL of 0.1 ppm by the exhaust ventilation. With or without ventilation, ozone concentrations became negligible soon after welding ceased. Ventilation had only a minimal effect on the concentration of carbon monoxide while the arc was on, but reduced it to negligible levels when welding ceased.

The maximum average fume concentration measured during the 6-minute welding operation was 83.6 mg/m^3 at 120 A. During this period, welding fumes were not effectively removed by ventilation which only reduced fume concentrations to about 57 mg/m^3. The fumes diminished rapidly once welding stopped. The time-averaged concentrations in the 24 minutes after the arc was turned off fell to about 9 mg/m^3 in the absence of ventilation and to about 4 mg/m^3 with ventilation. Time-averaged fume concentrations during the entire 30-minute monitoring period were 24 mg/m^3 without ventilation and 15 mg/m^3 with ventilation. The authors concluded that, although air duct ventilation was not very effective during the time of actual welding, it was effective in exhausting residual contaminants after welding ceased. The relative ineffectiveness of LEV in this experiment, compared with that of Wurzelbacher (Ref. 164) may be related to the much greater ventilation rate, measured in air changes per minute, in the latter study.

Mathematical modeling and further experimental work with the same laboratory apparatus (Ref. 130) demonstrated that an exhaust hood installed at the height of the welder's breathing zone was more effective in reducing fume concentrations in the breathing zone than was similar exhaust ventilation placed in the vicinity of the weld. An additional benefit of the breathing zone ventilation system was that it produced no "blowholes," while many such defects in the weld were found when the exhaust port was located close to the weld. The investigators also found that conditions such as welding current and type of welding wire must be considered in the determination of the optimum exhaust flow rate.

Wallace and Fischbach (Ref. 155) compared the effectiveness of two types of local exhaust units during SMAW of stainless steel. Tests designed to simulate boiler repair welding were conducted at a training facility for apprentice welders. Breathing zone samples were collected during active welding from the three welders who participated in the study. Most of the samples were taken outdoors, inside a semi-enclosed tank, but two were taken inside a building, near a partially-opened garage door. The LEV units tested were the MEF, a mobile wheeled fume extractor unit with a 2-meter flexible arm, and the BSFR-2101, a portable fan unit on a support stand with a flexible arm.

Breathing zone exposures were lower when the MEF unit was used than when there was no LEV, but the differences were not statistically significant. However, the BSFR unit, which was found to have better capture velocities than the MEF, caused a significant reduction ($p < 0.02$) in exposures to fumes and Cr(VI) compared with those measured with the MEF unit or with no LEV. A comparison of fume exposures when welding indoors with and without LEV, showed that the BSFR could effect an 80% decrease in fume exposure.

In the absence of ventilation, the welder's posture during welding was shown to be an important determinant of breathing zone exposures. In this study, a welder who stood erect, with his face directly over the face plate, had significantly higher exposures to welding fumes than did a second welder who stood bent at the waist, resting his arms on the workhorse, keeping his face out of the welding plume. The authors noted that, when welding is done outside, the ability of the welder to stand upwind of the welding plume may be more important than the use of LEV.

In a separate study, Wallace et al. (Ref. 157) compared exposure levels during FCAW of carbon steel and GMAW and GTAW of stainless steel in a plant that manufactured commercial steam ovens. At the time of the study, exhaust ventilation was not used during welding of stainless steel, but fume extraction guns connected to a central vacuum exhaust system were used during carbon steel welding. Two types of fume-extraction guns were used. The first incorporated the ventilation line in the gun itself, in a single casing with the shielding gas line. The second had a separate exhaust connected to a suction device mounted on the gun nozzle. Some welders found the all-in-one extraction gun to be cumbersome and chose to work with the conventional gun. Personal samplers were worn by four stainless steel and four carbon steel welders. Exposures to total particulate were almost six times higher with FCAW than with GMAW and about 60 times higher with FCAW than with GTAW (see Table 4).

Table 4
Breathing Zone Particulate Concentrations by Welding Process

Welding Process	n	Mean (mg/m^3)	Std. Dev.	Range
FCAW (carbon steel)	20	8.97	12.0	1.17–55.46
GMAW (stainless)	11	1.61	0.73	0.49–2.67
GTAW (stainless)	10	0.16	0.07	0.06–0.27

n = number of samples.

Source: Data from Wallace et al., Ref. 157.

Differences in welding fume exposure received by two welders performing FCAW of carbon steel using the same type of ventilation appeared to be related to differences in their work practices. One welder, concerned that the ventilation might remove the shielding gas and thus weaken the weld, moved the suction device higher to reduce the air flow at the weld. He also observed that the ceiling fan over his workstation created turbulence which interfered with the exhaust. Facing the same problem, the second welder achieved a lower exposure to welding fumes by increasing the shielding gas flow rather than reducing the exhaust ventilation rate.

Comparison of the breathing zone fume concentrations with and without ventilation during FCAW showed that there was a significant decrease in fume concentration when ventilation was used; but, even with the use of LEV, mean breathing zone levels of welding fumes from FCAW were much higher than the average concentrations from GMAW and GTAW. None of the welders' exposures to select metals exceeded the PELs during GMAW and GTAW, but four welders of carbon steel had exposures higher than the TLV for manganese (0.2 mg/m^3), even when exhaust ventilation was used. Wallace et al. concluded that the welding method is the most important factor in determining welding fume exposures and recommended that FCAW should be replaced, when possible, by welding processes that produce less fumes. Secondary factors are the composition of the base metal, the welder's position relative to the fume, and the type and effectiveness of LEV.

Guffey et al. (Ref. 46) and Simcox et al. (Ref. 132) evaluated the effectiveness of newly-installed LEV systems that were designed to reduce the excessive exposures to cobalt and cadmium that had been previously documented in three areas of a hard metal[2] tool re-sharpening shop. Brazing, dry grinding, and welding were used to repair round saws in one of these areas. Wet grinding during repair of round saws was the primary activity in another area. In the third area, dry grinding was performed on Stellite[3] and steel band saws, and a welder/annealer was used to repair the tips of the Stellite saws. Personal exposures to cadmium and cobalt were measured just before the new ventilation systems were installed and on a monthly basis for a year thereafter. The local exhaust units were monitored concurrently with the personal exposure measurements from the time the exhaust systems were installed in an effort to determine how upkeep of the equipment influenced worker exposure.

Over the 12 months of the study, air flows generally declined due to inadequate maintenance. The greatest declines were associated with grinding, which quickly filled ducts with clumps caused by a sticky resin that was part of the binder in the grinding wheels. Even though the exhaust equipment was poorly maintained during the study period, cadmium and cobalt exposures dropped substantially for most of the workers after installation of the LEV system.

Two Stellite grinder/welders, two brazers, and four workers involved exclusively with grinding took part in the study. The Stellite grinder/welders consistently had the highest exposures to cobalt. The grinder/welder who worked in the band saw area had the highest cobalt exposure, which was attributed, in part, to his frequent removal of the exhaust hood in order to side dress the grinding wheels. In addition, part of his exposure was thought to have arisen from a nearby welding/annealing machine which was only partially ventilated. For the other workers, the new ventilation system led to a substantial reduction in cobalt exposures. Cadmium concentrations were greatly reduced for all of the workers except the two brazers. Variability in cadmium exposures among these workers was attributed to differences in their work practices and in their use of the exhaust hoods. The authors concluded that the installation of LEV was sufficient to control worker exposures at most workstations.

Niemela et al. (Ref. 98) investigated the performance of displacement ventilation in a large industrial hall where furnaces and cylindrical tanks were manufactured for the chemical and pulp and paper industries in Finland. Air was evacuated through two exhaust fans on the roof and introduced into the building through seven inlet air diffusers at ground level. Field measurements were designed to yield information on stratification patterns of welding fumes and particulate matter generated in stainless steel welding and related operations. Much of the welding was FCAW of stainless steel, but automatic welding machines were also used. Airborne contaminants were measured in personal breathing zone samples collected from six workers, in area samples taken at fixed positions 1.5 meters above the factory floor, and in area samples taken on masts in the upper levels of the hall high above the work area.

Concentrations of total dust, Cr(VI), trivalent chromium [Cr(III)], and nickel in the area samples were generally well below their respective occupational exposure limits. Concentrations of particles in personal samples were up to ten times those in the area samples. When welding

[2] Hard metal is an alloy containing tungsten carbide and 6 to 7% cobalt.

[3] Stellite is an alloy containing primarily cobalt, chromium, and tungsten.

was performed in enclosed spaces, the concentrations of Cr(VI) and total particulate were up to 100-fold higher in personal samples than in general area samples and the average breathing zone values were frequently above the occupational exposure limits. There were great differences in vertical stratification of the contaminants, particularly Cr(VI), which was notably lower on the factory floor than in samples taken high above the working area. The authors noted that the only source of Cr(VI) in that factory was welding, which produces fumes of about 1 μm in diameter—small enough to be easily carried upwards and away from the working area by displacement ventilation. Larger particles, such as those generated by grinding and polishing, tended to remain in the working level of the hall. The authors concluded that while the displacement ventilation effectively protects workers who are not actively welding, welders must still be equipped with respirators during welding in regions where the air is stagnant or in enclosed spaces.

6.2 Compliance with Health and Safety Regulations. Walls and Dryson of the New Zealand Occupational Safety and Health Service (OHS) audited compliance with new health and safety legislation in New Zealand by 299 randomly selected manufacturing companies that used welding processes (Ref. 158). The audits were conducted 5 years after the regulations were enacted into law and 2 years after the OHS mounted an information campaign concerning hazards associated with welding and recommended control measures. The audited companies employed a total of 1947 welders. There was an average of 6.6 employees per company, and 86% of the companies employed ten or fewer workers and were classified as "small employers."

GMAW was used by 34% of the companies, followed by SMAW (25%), GTAW (20%), oxygas cutting (18%), and plasma arc welding (2%). Several companies used multiple techniques. The overall finding was that noncompliance was prevalent regardless of company size. Only 10% of small employers and 14% of large employers used local exhaust ventilation for all of the welding processes; 22% of the companies, both large and small, used no LEV. Only 11% of the companies surveyed had effective ventilation in all areas where welding occurred. One-third of the companies had what the authors considered to be a satisfactory system for welding in confined spaces. Satisfactory eye protection was used by 93% of the welders but effective respirators were only used by 50%. The investigators concluded that self-regulation, which the health and safety laws had been designed to encourage, was not successful among small businesses in New Zealand.

6.3 Accidents and Injuries. Shaikh examined the prevalence of occupational injuries among 208 welders and 104 lathe operators employed in Rawalpindi and Islamabad, Pakistan (Ref. 128). An injury was defined as an incident requiring medication or treatment with a topical ointment; data were obtained by interview. All of the workers surveyed had learned their trades on the job and none had any formal education. Their average age was 30 years and all were experienced in their trade. Half the welders performed oxyacetylene welding.

Thirty-nine (19%) of the welders and 27 (26%) of the lathe operators reported having sustained an injury in the 3 months preceding the interviews, while 63 (30%) of the welders and 76 (73%) of the lathe operators reported being injured during the last twelve months. The most common types of injuries were burns on the face, limbs, or trunk, and foreign bodies in the eye (see Table 5). Most of the incidents involved multiple injuries and, in six cases, permanent disfigurement or some loss of function resulted from the accident. In all, 93 workdays were

Table 5
Occupational Injuries Experienced During a 3-month Period by Welders and Lathe Machine Operators

	Welders		Lathe Operators	
Type of Injury	No.	%	No.	%
Foreign body in the eye	29	40.3	18	66.7
Injury on arms or hands	0	0	8	29.6
Facial injury or burns (other than eyes)	16	22.2	1	3.7
Burns on limbs or body	27	37.5	0	0

Source: Data from Shaikh, Ref. 128.

lost among the welders during the 3 months preceding the interview.

Despite the frequent injuries, only half of the welders considered their occupation to be hazardous. Protective devices such as goggles and gloves were used by 54% and 6.7% of the welders, respectively; 21.6% stated that they never used protective devices. First aid boxes in the workplace were available to 48 of the welders and only 10 had access to fire extinguishers. Shaikh concluded that there is a need in Pakistan for the formulation and enforcement of safety regulations and for preventive education.

Hierbaum described an accident in which a welder was working on a combustion turbine below a group of iron workers who were assembling a large structural steel tank (Ref. 55). Without warning, the air hose broke free from the air-driven impact wrench being used by the iron workers. The hose whipped around uncontrollably and the welder was hit in the face by the metal coupling on the end of the hose. The welder had been wearing goggles which, though they were severely mangled, spared him from eye injuries. His escape from serious injury was attributed to the goggles exceeding the requirements of the American National Standards Institute for protective eyewear.

Musa (Ref. 97) described an incident in Nigeria in which a man was welding a metal drum that exploded and hit a nearby child, severing his leg at the knee. The author explained that containers used for storage of gasoline or kerosene are often bought for use in the home. They must be welded if they have leaks. Apparently, the residual fluid had not been removed from the drum so the heat developed during welding vaporized the fuel and caused the explosion.

Section Two
Effects of Welding on Human Health

7. Respiratory Tract

7.1 Pulmonary Function. Pulmonary function tests detect conditions in which airflow through the respiratory tract (obstructive lung disease) or the capacity of the lungs to hold air (restrictive lung disease) is impaired. Obstructive lung diseases, such as asthma, emphysema, and chronic bronchitis, are characterized by a decrease in the exhaled air flow caused by a narrowing or blockage of the airways. Emphysema involves both airflow obstruction and oxygenation problems due to abnormal inflation of the alveoli and damage to their walls, which reduces the ability of the lung to transfer oxygen into the blood. Restrictive lung diseases, such as fibrosis and interstitial lung disease, are usually due to decreased elasticity of pulmonary tissue, but may also be caused by an impaired ability to expand the chest wall during inhalation.

Decrements in lung function can be detected using spirometric tests which measure lung volume, the maximum amount of air that can be inhaled, and the flow rates that can be achieved after a maximal inhalation. Parameters measured by pulmonary function tests include: forced expiratory volume (FEV_1), the volume that can be exhaled in one second; forced vital capacity (FVC), the maximum volume of air that can be inhaled and exhaled (reduced in restrictive lung disease, and to a lesser extent in obstructive disease); and FEV_1/FVC, the ratio of the previous two, which is reduced in obstructive disease, but not in restrictive disease. These and other pulmonary function measurements frequently used in epidemiological studies of workers are described in greater detail in Appendix A.

Erhabor et al. (Ref. 36) evaluated the pulmonary function and general health of arc welders who worked in a suburb of Ile-Ife, Nigeria. Physical examinations and lung function tests were administered at the work sites of 44 arc welders and 50 university maintenance workers who served as controls. Most of the welders worked in poorly ventilated roadside workshops. They rarely used respirators, goggles, or other protective devices because the hot, humid work conditions made the use of protective equipment, when available, uncomfortable. Demographic data, occupational histories, medical symptoms, and histories of personal habits such as smoking were obtained via questionnaire. Medical symptoms, including eye and skin irritation, rhinitis, and cough were reported in significantly greater numbers by welders than by controls (see Table 6). Lung function was normal in 16 (26%) of the welders and 46 (92%) of the controls. The mean values for peak expiratory flow rate (PEF), FEV_1, FVC, and FEV_1/FVC were all significantly decreased in welders compared with controls. Restrictive lung disease, defined by the investigators as FVC less than 80% of predicted value accompanied by a normal value for FEV_1/FVC, was found in 18 welders (41%) and in none of the controls. Ten (23%) of the welders had obstructive lung disease (FEV_1/FVC less than 70%) compared with 4 (8%) controls. The mean duration of employment as a welder was 13 years. Ten of the 18 cases of restrictive disease were seen in welders with less than 9 years employment, but none of the ten cases of obstructive disease was seen in this group.

Table 6
Symptoms Reported by Welders and Controls (Maintenance Workers) in Ile-Ife, Nigeria

	Welders	Controls
Number of subjects	44	50
Symptom		
Eye irritation	42	0
Rhinitis	26	0
Skin irritation	19	0
Productive cough	13	7
Dizziness	10	0
Back pain	10	0
Chest pain	5	3
Chest tightness	1	0

Source: Data from Erhabor (Ref. 36).

7.2 Asthma. Asthma is an obstructive airways disease in which the smooth muscle lining the bronchi goes into spasm, and the bronchi and bronchioles become inflamed and mucous-filled, causing the airways to narrow, blocking air flow to the lungs. From a review of the published literature, Toren et al. (Ref. 150) estimated that 5% to 15% of adult-onset asthma may be caused by occupational exposures. Estimates of the occurrence of occupational asthma (OA) have varied from about 40 cases per million workers in a British survey, based on voluntary reporting by selected physicians, to 153 per million in Finland, where reporting of occupational diseases is mandatory. Toren et al. proposed a working definition of OA: confirmed asthma with temporally-related occupational exposure to agents or conditions known to cause or substantially aggravate asthma, or an association between asthma and work defined by any of (1) temporal relation between symptoms and work, (2) significant work-related changes of FEV_1 or PEF, or work-related changes in airways responsiveness to non-specific inhalation challenge, (3) positive response to inhalation challenge with an agent from the workplace environment, or (4) onset of asthma or substantial aggravation of asthma immediately following high exposure to respiratory tract irritants in the workplace. Three categories of causative agents for OA were listed: high-molecular-weight compounds, which are mainly of biological origin, such as flour and grain dusts, latex, enzymes, and animal dander; low-molecular-weight compounds such as acids, anhydrides, isocyanates, and dyes; and irritants such as acrylates, chlorine, and sulfur dioxide. Toren et al. noted that an association between stainless steel welding and OA has been observed in some studies. Although the association between OA and welding of mild steel was less strong, the authors suggested that such a link might exist. In addition, isocyanate monomers, which are known triggers for asthma, can be liberated from polyurethane paints during welding of painted steel.

Using data retrieved from the Finnish Register of Occupational Diseases, Karjalainen et al. (Ref. 63) determined the incidence of OA in Finland by occupation, industry, and causative agent for the years 1989–1995. In a population of 1,107,586 male workers between 20 and 64 years of age, there were 1314 newly-reported cases of OA during the 7-year period of the study, with a mean annual incidence rate of 17 per 100,000. The annual incidence rate of OA among the 12,762 men in the occupational group designated as "welders, flame cutters, etc." was 76 per 100,000. The annual incidence rate for OA was similar among the 1,031,178 women in the study (incidence rate = 18/100,000), but there were no cases of OA among the 572 female welders. When the incident cases[4] of OA among men and women combined were ranked by causative agent, 37.7% were caused by animal epithelia, hairs, or secretions, followed by flours, grains and fodders (22.3%), mites (5.3%), isocyanates (4.8%), and welding fumes (4.4%). Exposure to welding fumes accounted for 8.1% of the OA in men. The authors noted that the national reporting system had an influence on these findings because cases associated with well-recognized causative agents were more likely to be compensated and, therefore, more likely to be reported.

In a continuation of this study, Karjalainen et al. (Ref. 62) examined the incidence of OA in Finnish construction workers from 1986 through 1998. Cases of OA were defined as men between the ages of 25 and 59 years, without pre-existing asthma, who received reimbursement for asthma medication from the Social Insurance Institution of Finland or were registered for compensation by the Finnish Register of Occupational Diseases. During the period of the study, 2548 cases of asthma were reported among the 108,549 construction workers. Of these cases, 45 had been recognized as OA. Fourteen of them were attributed to welding fumes, which accounted for more cases of OA than any other exposures among construction workers. Other exposures associated with multiple cases of OA were wood fumes (9 cases), isocyanates (6 cases), synthetic resins or plastics (3 cases), and stainless steel grinding dust (2 cases).

To calculate the relative risk (RR) for adult-onset asthma from all causes, construction workers were placed into

[4] Incident cases: All new cases of the condition or disease under study identified within a specific population during a specified time period.

24 groups according to their trades and compared with a population of administrative, managerial, and clerical workers. There was a statistically significant relative risk for adult-onset asthma in 18 of the 24 occupational groups into which construction workers had been placed. The 1614 welders and flame cutters had the highest relative risk of asthma of all construction workers in the study (cases = 56, RR = 2.34, CI[5] = 1.79–3.06), followed in descending order by asphalt roofing workers (RR = 2.04), plumbers (RR = 1.9), painters and lacquerers (RR = 1.75), motor vehicle drivers (RR = 1.71), and construction carpenters (RR = 1.51). In separate analyses, the investigators demonstrated that the excess risk for asthma among construction workers could not be linked to socio-economic class or to smoking habits. The cases recognized by the State and compensated for OA represented only a small portion of the excess risk for adult-onset asthma among construction workers. The authors suggested that much of the excess incidence of asthma in construction workers is likely to be occupational asthma that has not been recognized as such.

Kor et al. (Ref. 69) performed a study of the incidence of occupational asthma in Singapore. Between 1983 and 1999, 90 new cases of OA were identified from the records of the Singapore Ministry of Manpower and through referrals to an occupational lung disease clinic in Tan Tock Seng Hospital. Isocyanate exposure was the causative agent in 28 (31.1%) of the cases, followed by soldering flux (12 cases, 13.3%), and welding fumes (8 cases, 8.9%). The median duration of exposure prior to onset was 12 months. The authors noted that, as the nation has become more technologically advanced, occupational asthma has overtaken silicosis and asbestosis as the most common occupational lung disease in Singapore.

Keskinen et al. described the case of a 47-year-old mechanic who experienced dyspnea (shortness of breath) and reddening and swelling of the face when he used GMAW to repair forest harvesters.[6] These reactions began within a few months after he started to work on this equipment. His PEF varied by 22% during a day on which he welded, and he exhibited slight bronchial reactivity. These symptoms recurred whenever he welded this machinery and diminished when he did other work. Exposures in the clinic to vapors from the chlorinated polyester paint with which the forest harvesters had been painted immediately elicited the same responses. His PEF dropped by over 30% when he was exposed to the vapors, which is strongly suggestive of asthma.

[5] CI = 95% confidence interval.

[6] Forest harvesters are large vehicles developed in Finland for cutting and hauling trees.

In the laboratory, heating metal sheets coated with the polyester paint with a propane torch released phthalic anhydride (PA) and chlorendic anhydride (CA) (Ref. 110). Both of these compounds are strong irritants and PA is a known sensitizer. The mechanic had strong positive reactions to PA and CA in skin prick tests. The clinical evaluation combined with the laboratory findings led to a diagnosis of OA resulting from the fumes generated by welding the painted metal.

Analysis of air samples collected during repair of forest harvesters confirmed that CA and PA are released in aerosols generated by welding metals coated with the chlorinated polyester paint (Ref. 110). Breathing zone samples collected from two workers while they were performing repairs on a forest harvester using GMAW with a mison shielding gas were found to contain 2 $\mu g/m^3$–44 $\mu g/m^3$ CA and 11 $\mu g/m^3$–21 $\mu g/m^3$ PA. The investigators suggested that while these levels are low, the concentrations of CA and PA fluctuate in the fumes and peak levels may have been high enough to have caused the observed health effects.

7.3 Pneumoconiosis. Pneumoconiosis, the accumulation of dust in the lungs, was originally diagnosed and characterized in the 1930s by chest X-ray. The radiographic appearance of the lungs and associated clinical symptoms vary with the physicochemical properties of the inhaled dusts. Siderosis, the accumulation of ferric oxide particles in the lungs (also referred to as welder's pneumoconiosis or welder's lung), has generally been considered to be a benign condition. It frequently regresses, with no impairment of lung function, after cessation of welding exposure. Computed tomography (CT) is more sensitive than chest radiography in depicting abnormalities associated with pneumoconiosis and is being used with increasing frequency for this purpose. In CT scans, siderosis typically takes the form of diffusely distributed spherical nodules that contain radioopaque iron particles that lie within macrophages. In more advanced cases, fine branching lines and accumulated micronodules form a networked pattern that is referred to as ground glass attenuation (Ref. 1).

Using thin section CT, Han et al. (Ref. 49) examined the lungs of 85 Korean arc welders who had filed claims for compensation for work-related respiratory symptoms (n = 74)[7] or abnormal chest X-rays (n = 11). The mean age of the welders, three of whom were women, was 44 years. The welders were compared with 43 smokers who had no welding experience and who had been subjected to CT scans for a variety of disorders. Pulmonary abnormalities were identified in the CT scans of 54 of the 85

[7] n = number of subjects.

welders (64%) and six of the non-welders (14%). This difference was statistically significant. The predominant findings in the CT scans of the welder's lungs were centrilobular micronodules and branched structures similar to those described above (Ref. 1). Pulmonary function tests, including measurements of FVC and FEV_1, were administered to the 53 welders who had responded to questionnaires and provided information concerning clinical symptoms, and occupational and smoking histories. Their mean exposure to welding fumes was 15 years; 42 (79%) were smokers, and 46 (87%) had experienced respiratory symptoms including dyspnea (n = 40), sputum (n = 33), and cough (n = 25). The extent of abnormalities observed in CT scans did not correlate significantly with the results of the pulmonary function tests, with the severity of dyspnea, or with the years of tobacco smoking among these welders. Furthermore, no differences were seen between the appearance of the CT scans of the lungs of the smoking and non-smoking welders indicating that the extensive pneumonoconioses observed in the welders were not related to smoking.

In a study of the prevalence of pneumoconiosis among workers in shipyard welding, stone grinding, and refractory crushing in Okayama, Japan, Takigawa et al. (Ref. 146) examined 1006 chest X-ray films taken during mandatory health examinations administered in 1999 and 2000. Signs of pulmonary abnormalities were seen in 174 (17%) of these films. The highest percent of films with abnormalities was found among welders (75.4%), followed by refractory crushers (53.1%) and stone grinders (16.1%). Most of the abnormalities seen in welders were not well defined cases of pneumoconiosis but, rather, were described as pre-pneumoconiotic conditions. Of the three trades, welders had the lowest percent of chest X-rays with more advanced cases of pneumoconiosis. There was a statistically significant correlation between the duration of the experience working in these trades and the prevalence of lung abnormalities. The authors concluded that more attention should be paid to the working environment and health and safety practices of welders with pre-pneumoconiotic lesions in order to prevent them from progressing to more advanced stages.

Interstitial pulmonary fibrosis[8] (IPF) is occasionally observed in radiographs of welders with long-term exposures to high levels of fumes. The relationship between siderosis and IPF is unclear. It may be a natural sequelae of long durations of intense exposure to welding fumes, it may be due to substances other than ferric oxide, or it may be due to mixed dust exposures. Early stages of IPF are marked by severe inflammation and mild derangements of the alveolar wall. Biopsies of middle and late stages show marked derangements of alveoli with less inflammation.

Buerke et al. (Ref. 21) observed IPF in chest X-rays and CT scans of 15 welders from West Germany who had had long durations of exposure to high levels of welding fumes in poorly ventilated workplaces. The mean age of the welders was 53 years and their mean duration of exposure to welding fumes was 28 years. One welder was a current smoker, nine were past smokers, and five had never smoked. They had no known exposures to the fibrogenic dusts asbestos or silica, but some had welded surfaces coated with paint or mineral oil.

All of the welders had X-ray findings of pneumoconiosis and clinical respiratory symptoms such as dyspnea and cough. Most had lung function abnormalities which were primarily indicative of restrictive impairment. CT scans and scanning electron microscopy (SEM) of lung tissue specimens revealed pulmonary fibrosis in ten of the welders. Energy dispersive X-ray (EDX) analyses of lung specimens showed high concentrations of Fe and lower quantities of S, Si, P, Al, and Ca in particles embedded in areas of fibrosis. Records were available for one welder who had been followed since the age of 25. For most of his 28-year welding career, he had worked in confined spaces with poor ventilation and no respiratory protection. By age 27, after 2 years of welding, chest X-rays showed profusions with rounded opacities, typical of siderosis. At that time, his lung function was normal and he had no respiratory symptoms. After 8 years, his chest X-rays showed opacities which had changed to a more irregular pattern compatible with IPF. By age 44, he had developed marked pulmonary fibrosis, and lung function tests revealed a restrictive ventilatory disorder with low static lung compliance and reduced diffusion capacity. Examination of a lung specimen showed marked fibrosis, with welding fume particles embedded in fibrotic tissues. In 1998, he received a lung transplant. The authors concluded that long-term exposure to high concentrations of welding fumes may lead to IPF.

Using light microscopy, scanning electron microscopy, and EDX, Muller and Verhoff (Refs. 95, 152) evaluated lung tissue samples obtained by biopsy or autopsy from 43 welders. Pulmonary alterations characteristic of pneumoconiosis were seen in samples from 38 of the men. The lesions ranged from simple siderosis, with iron deposits in macrophages, to extensive interstitial fibrosis. Examination of samples from seven of the welders revealed siderosis with iron oxide laden macrophages found mostly in alveoli but also in the interstitial tissue. Siderosis with signs of fibrosis and large accumulations of macrophages was seen in areas with mixed dusts in

[8] In interstitial pulmonary fibrosis, the tissue between the alveoli (the interstitium) becomes scarred by fibrotic tissue.

lung tissue samples taken from 21 of the men, and advanced fibrosis with associated deposits of welding fume particles were seen in samples from ten of the men. Analysis by EDX revealed deposits of Al, Ti, Cr, Ni, and Fe within macrophages in samples with and without fibrosis. The investigators concluded that the level of impairment related to welders' lungs can only be evaluated when occupational history, microscopic findings, and clinical/functional parameters are considered together.

Yoshii et al. (Ref. 165) assessed whether the concentration of ferritin, an iron-carrying protein, in serum and bronchoalveolar lavage fluid (BALF) could be used as a diagnostic indicator for pneumoconiosis in welders. Ferritin levels were determined in samples collected from eleven patients who had welder's pneumoconiosis but no signs of pulmonary fibrosis. These values were compared with those from six welders who did not have pneumoconiosis and with those from seven non-welders who had pneumoconiosis associated with silica or asbestos exposure.

Deficits in pulmonary function were seen in 3 of the 11 welders with pneumoconiosis. Ferritin was higher than normal in serum from 10 of the 11 welders and was elevated in BALF from 8 of the 9 welders from whom BALF was obtained. There was no correlation between concentrations of ferritin in BALF and serum or between concentrations of ferritin in BALF and the severity of the welder's pneumoconiosis. Ferritin was significantly higher in BALF from welders with pneumoconiosis than it was in welders without pneumoconiosis or in patients with pneumoconiosis associated with silica and asbestos exposures. Four of the welders with pneumoconiosis had disease conditions (hepatitis and/or nontuberculous mycobacteriosis) which may have complicated the results. When these four welders were removed from the analysis, ferritin concentrations were still significantly higher in the seven welders who had pneumoconiosis without complications than in the welders with no pneumoconiosis or in the patients with asbestosis or silicosis. The authors concluded that measurements of ferritin in BALF may be useful for early diagnosis of welder's pneumoconiosis.

7.4 Case Reports—Pneumoconioisis. The case of a 38-year-old man who suffered from shortness of breath and spontaneous pneumothorax, a condition in which a pocket of air forms between the outer lining of the lung and the chest wall causing collapse of the lungs, was described by Strobel (Ref. 141). The patient was hospitalized and was treated by placement of chest tubes. He was an arc welder with a history of cigarette smoking. Lung biopsy revealed an abundance of macrophages which contained coarse brown-black foreign particles and birefringent pointed spicules up to 5 m in length. His condition was diagnosed as siderosilicosis, a mixed-dust pulmonary fibrosis presumably resulting from mixed exposures to welding fume and silica dust.

Two aluminum welders who died from complications of extensive aluminum pneumoconiosis were described by Hull and Abrahams (Ref. 58). Both men were in their mid-40s and had worked in confined spaces without the benefit of respiratory protection at the same shipbuilding company in Louisiana. The first of these welders had been involved with welding and grinding aluminum for 16 years followed by 8 years of arc welding aluminum. He sought medical help when he experienced chest pain and fever. Chest X-rays revealed a pneumothorax, diffuse bilateral infiltrates, emphysema, and severe fibrosis. Pulmonary function tests showed a 46% reduction in FVC. He was misdiagnosed with and treated for sarcoidosis (a condition in which granulomas, collections of inflammatory cells, form in organs throughout the body). He returned for treatment a few months later again with chest pains, and was treated for a large pneumothorax that nearly caused collapse of the right lung. Over the next several years his condition worsened and chest X-rays showed progressive disease. He was placed in the hospital where he died from aspergillus pneumonia.

The second welder had been involved with aluminum welding throughout his 22-year career. He had been a heavy smoker and suffered from progressive dyspnea, severe hypoxia, and narcolepsy. His chest X-rays showed bilateral diffuse small densities, pleural thickening, and mild heart enlargement. Pulmonary function tests revealed reductions in FVC and moderate air flow obstruction. He died from lung cancer.

Scanning electron microscopic analysis of lung specimens from the welders revealed an average of about 9.3 billion aluminum particles per cm^3 with an average diameter of about 0.4 μm. This was the highest concentration of particles seen among 812 similar analyses stored in a pneumoconiosis database. In the first welder, 86% of the particles contained aluminum and 3% contained aluminum silicates. Particles containing silica (0.9%) and gypsum (8.0%) were also found. In lung specimens from the second welder, 98% of the particles contained aluminum and 0.9% contained aluminum silicates. The authors concluded that smoking may have contributed to the pneumoconiosis in the second case, but probably not in the first welder who had been a very light smoker.

7.5 Absences Due to Respiratory Symptoms. Alexopoulos and Burdorf (Ref. 2) performed a longitudinal study in the Netherlands of the frequency and duration of absences from work resulting from respiratory disorders.

The study included 97 welders, 125 metal workers, and 29 office clerks from two construction companies. The welders were involved full-time with welding and 90% of the metal welded was mild steel. At the start of the study, the subjects were interviewed to determine whether they suffered from asthma, chronic obstructive pulmonary disease (COPD) indicated by chronic cough or phlegm, or chronic non-specific lung disease (CNSLD), indicated by chronic cough, chronic sputum secretion, wheezing, shortness of breath, or attacks of chest tightness. Spirometric tests were administered to each subject to measure FVC and FEV_1. During the next 2 years, all absences and symptoms experienced during the absences, as reported by the subjects, were recorded.

At the start of the study, welders reported a significantly higher prevalence of CNSLD, but not asthma or COPD, than did the other workers. During the 2-year follow up, respiratory complaints were responsible for 14.2% of the days off from work and 35% of the workers attributed at least one period of absence to respiratory complaints. The rate of absence was 21% due to CNSLD, 17.5% for COPD, and 10.5% for asthma.

Age, body mass, and smoking were not related to absences due to respiratory ailments. Reduced FVC and complaints about asthma but not COPD or CNSLD at the start of the study period were significant predictors of absence during the follow-up period. Duration of employment had a slight protective effect and was a weak predictor against absenteeism due to respiratory illness. Office workers had fewer periods of absence due to respiratory illness and returned to work more rapidly after such an absence than did welders or metal workers.

7.6 Respiratory Tract Infections. Aviles et al. (Ref. 8) described a 52-year-old man who had worked as a welder all of his adult life. He reported to the emergency room after 2 days of fever, rigors, cough, and shortness of breath. He was admitted to the hospital where he was diagnosed with streptococcal pneumonia. He died within 24 hours after admission. This was his fourth bout of pneumonia within a 15-year period. The authors cited the work of Coggon et al (Ref. 22) which showed that welders have an increased risk of dying from pneumococcal pneumonia. Neither the incidence of pneumonia nor the risk of dying from it remain elevated in welders after they retire. Aviles et al. postulated that the increased susceptibility to pneumonia in active workers may be related to toxic effects of inhaled fumes on alveolar macrophages or upon other aspects of the immune system.

Mizuhashi et al. (Ref. 93) described the cases of two welders with nontuberculous mycobacterial lung infection. Both reported to the hospital with abnormal radiographic thoracic shadows and productive cough. Computed tomography of both men revealed mild cases of welder's pneumoconiosis with deposits of welding particulate. The first patient was 37 years old and had worked as a welder for 7 years. Bacterial culture of a sputum sample indicated Mycobacterium avium infection. Shadows suggestive of mycobacterium infection were seen by CT. The patient was treated for nontuberculous mycobacterial lung infection over a period of 18 months. Seven months after completion of the treatment, his symptoms reappeared. Eventually he successfully resumed the treatment and the CT shadows related to the disease subsided and sputum tests for mycobacterium were negative.

The second patient was a 52-year-old man who had been employed as a welder for about 30 years. Bacterial culture of sputum revealed Mycobacterium kansasii. He originally refused treatment, and, within a few months, evaluation by CT revealed that shadows indicative of mycobacterium infection had worsened. Eight months after his initial evaluation he began treatment and his symptoms were alleviated within 2 months. Treatment continued for 18 months and, unlike the first patient, he suffered no relapse.

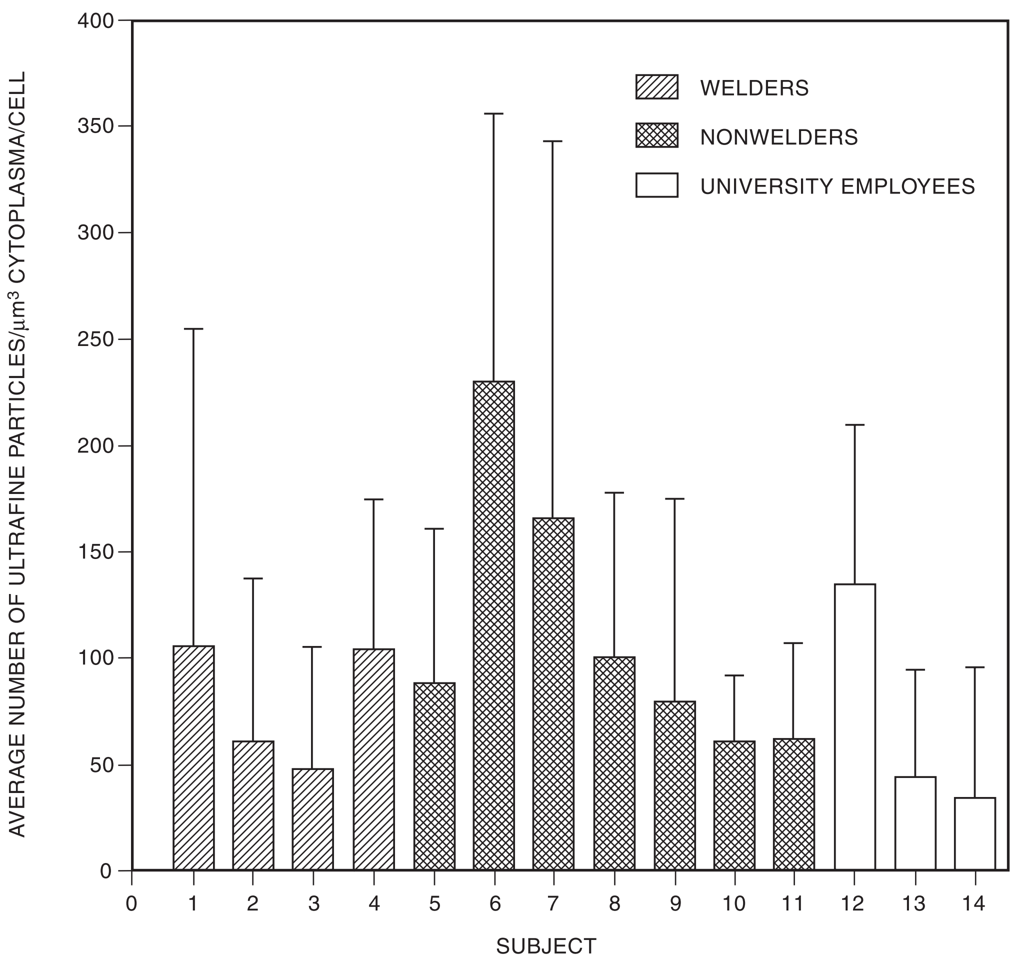
The authors noted that nontuberculous mycobacterial lung infection is a rare complication of pneumoconiosis. They cited the work of Gomes et al. which showed that, in mice, the intracellular bactericidal activity of macrophages against Mycobacterium avium is reduced in the presence of excessive iron (Refs. 43, 44). Based in part on that work, they postulated that the ingestion of inhaled iron oxide particles by macrophages may affect the body's defense against mycobacteria infection, altering its clinical features and encouraging the development of infection.

Wergeland and Iverson (Ref. 160) noted that the Norwegian Labor Inspection Authority issued a warning to physicians about the potential severity of pneumonia in men exposed to welding fumes. Patients with welding exposures should be hospitalized because, while pneumonia is not usually lethal in middle-aged men unless there is some underlying disease, reports of illnesses have indicated that the inhalation of welding fumes may seriously aggravate the prognosis for this disease.

7.7 Particle Size. The size and shape of inhaled particles determine the location in the respiratory tract where they may be deposited. Respirable particles are smaller than 10 µm in diameter and can be deposited in the trachea and bronchi. Fine particles equal to or smaller than 2.5 µm in diameter ($PM_{2.5}$) are among the most hazardous because they can be deposited in the gas exchange areas of the lungs (the alveoli). Researchers have recently focused attention on ultrafine particles (aerodynamic diameter less than 0.1 μm), which may be more toxic than fine particles ($PM_{2.5}$), in part, because they can be more readily translocated into the pulmonary interstitium and may be cleared more slowly from the lungs.

Large quantities of fine and ultrafine particles are generated by arc welding (Zimmer). Based on the premise that particles retained in alveolar macrophages may serve as markers of exposure to ultrafine particles, Hauser et al. (Ref. 50) examined the ultrafine particulate content of macrophages present in BALF withdrawn from eleven power plant workers, four of whom were welders, and three non-exposed university employees. Pulmonary function tests were performed on ten of the utility workers and none of the university employees. Seven of the subjects had a history of smoking but none were current smokers.

Ultrafine particles were found in macrophages obtained from all volunteers. The average number of ultrafine particles per μm^3 cytoplasm per cell for each subject is shown in Figure 2. The average number of ultrafine particles in alveolar macrophages was not significantly associated with occupation and was independent of occupational exposure to welding fumes. Among past smokers, there was no association between pack years smoked and the average number of ultrafine particles. The average number of intracellular ultrafine particles in alveolar macrophages was negatively associated with lung function. The authors concluded that environmental expo-



Note: Error bar represents standard deviation.

Source: Hauser et al., Ref. 50.

Figure 2—Quantification of Ultrafine Particles in Alveolar Macrophages

sures may contribute more than industrial exposures to the ultrafine particulate burden in the respiratory tract. They noted that their study population was small and that the negative association between the number of fine particles retained in macrophages and lung function requires confirmation in larger studies.

Using a portable nephelometer (an instrument that measures light scattering by suspended particles), Frosig et al. (Ref. 39) measured the mass concentration of particles smaller than 2.5 µm ($PM_{2.5}$) in the breathing zone of welders. The fraction of these particles deposited in the lungs of the welders was calculated by measuring $PM_{2.5}$ in both inhaled and exhaled air. Six male welding instructors (3 smokers and 3 non-smokers) participated in the study. For the deposition measurements, the subjects were asked to breathe normally and then to inhale deeply and exhale completely. The fraction of particulate matter deposited in the lungs was the $PM_{2.5}$ in the inhaled air minus the $PM_{2.5}$ in expired air divided by that in the inhaled air. Daily deposition of particles was calculated using this figure and the subject's measured average minute ventilation.

Nephelometry in the workplace was conducted during SMAW, GMAW, GTAW, grinding, concrete work, and in the lunch room and office. The estimated breathing zone concentrations of fine particles are shown in Table 7. The pulmonary deposition of fine particles decreased significantly with increasing particle concentration. The fraction deposited also increased from about 10% during shallow breathing to 60% after maximum inhalation. The three smokers had decreased lung capacities compared with the non-smokers. The estimated total daily $PM_{2.5}$ deposition in non-smoking welders was about 1 mg. Smokers retained significantly more fine particles than non-smokers. The greater variance in fine particle deposition within subjects than between subjects made it difficult to interpret the findings of this study. The authors concluded that nephelometry during vital capacity breathing may be a useful tool, but they cautioned that careful attention must be paid in future studies to essential lung function variables, including tidal volume and respiratory frequency.

8. Cancer

Puntoni et al. (Ref. 113) conducted a historical cohort mortality study[9] among 3959 workers involved in ship repair, refitting, and construction in a shipyard in the harbor of Genoa, Italy. The subjects had been employed at, or retired from the shipyard between 1960 and 1981. They were followed until 1996, during which time there were 2376 deaths.

The numbers of deaths from various causes in the cohort were compared with the expected numbers of deaths derived from cause-specific mortality rates in the male population of Genoa to compute Standardized Mortality Ratios (SMRs—the ratios, expressed as a percentage, between the observed and expected number of deaths). Standardized Mortality Ratios were significantly increased for respiratory tract disease among electric arc welders (SMR = 221, $p < 0.05$) and for all cancers among oxyacetylene gas welders (SMR = 156, CI = 113–209). Non-significant increases in deaths from lung cancer were observed among both electric arc welders (SMR = 164) and gas welders (SMR = 157). Deaths from kidney cancer were non-significantly elevated among

[9] See Appendix B for definitions of epidemiological terms.

Table 7
Concentrations of Fine Particles ($PM_{2.5}$) at Various Sites in a Welding Workplace

Worksite	Measurement Time (hr)	Average $PM_{2.5}$ Concentration (µg/m^3)	Concentration Range (µg/m^3)
SMAW	5	70	21–145
GMAW	13	30	14–130
GTAW	4.5	22	15–155
Grinding during SMAW	3.5	36	15–130
Grinding during GTAW	5	19	14–35
Concrete work	5	22	12–140
Lunch room	4	44	16–140
Office between SMAW and GMAW worksites	3.5	75	48–190

$PM_{2.5}$ = particulate matter with a diameter of 2.5 µm or less.

Source: Data from Frosig et al., Ref. 39.

electric arc welders and gas welders, when the two groups were considered separately. When the data from the two groups of welders were combined, the increase in the number of deaths from kidney cancer became statistically significant (SMR = 382, CI = 124–981).

8.1 Lung Cancer. In 1991, Steenland et al. reported that a mortality study of 4459 mild steel welders did not show a significant excess of lung cancer in welders compared with 4286 non-welders who worked at the same plants or with the U.S. general population (Ref. 139). At the end of the first follow-up period (mid-1950s through 1988), the SMR for lung cancer was 107 (CI = 76–146) for the welders and 117 (CI = 92–147) for the non-welders.

In 2002, Steenland (Ref. 138) published the results of a second follow-up of these two cohorts. During this 10-year follow-up period (1989–1998), 108 welders and 128 non-welders died from lung cancer. At the end of the second follow-up period, the SMR for lung cancer for welders had increased to 146 (CI = 120–176) while that for non-welders was unchanged (SMR = 118, CI = 98–140). The ratio of lung cancer death rates between welders and non-welders was 1.22 (CI = 0.93–1.59), indicating that welders had a non-significantly greater proportion of deaths from lung cancer than did non-welders. In neither follow-up did the risk of death from lung cancer increase with the duration of welding exposure. (A positive exposure/response relationship would have strengthened the likelihood of a causal relationship between the exposure and the disease.) Analysis of data concerning tobacco use indicated that a modest excess of lung cancer among the welders was greater than that expected from differences in smoking habits between the welders and either the non-welders or the US population. Steenland's analysis indicated that the differences in smoking rates were likely to have accounted for at least part of the increased lung cancer incidence among welders. Based on the lack of significant differences in rate ratios for lung cancer between the welders and non-welders, and the likely contribution of smoking to the excess cancer risk of the welders, Steenland concluded that the additional 10-year follow-up showed "suggestive, but non-conclusive evidence" of an excess of deaths from lung cancer in this mild steel welding cohort.

Gustavvson et al. (Ref. 47) conducted a case-referent study to examine the risk of lung cancer associated with occupational exposure to diesel exhaust, mixed motor exhausts, other combustion products, asbestos, metals, oil mist, and welding fumes. The 1042 cases were 40 to 75-year-old men with lung cancer identified in the regional cancer register of Stockholm County, Sweden, between 1985 and 1990. The 2364 age-matched male referents were randomly selected from the general population. Data concerning occupational exposures, tobacco use, and exposure to environmental pollutants and residential radon were obtained by questionnaire and telephone interview. The relative risks for lung cancer were significantly elevated among men exposed to diesel exhaust, combustion products, and asbestos, but not among men exposed to welding fumes, metals, or oil mist. The investigators concluded that their study did not provide evidence for an association of lung cancer with mild steel welding which, they stated, is the predominant type of welding used in the Stockholm area.

Danielsen et al. (Ref. 26) investigated the incidence of lung cancer in a cohort of 4480 workers in a Norwegian shipyard that serves the North Sea oil industry. The study cohort included 861 welders. GMAW and GTAW of stainless steel were the primary procedures used after the mid-1970s; SMAW of mild steel was the predominant procedure before that time. Surveys conducted at the shipyard in 1976 and 1984 showed about 10% more smokers among the welders and shipyard production workers than among the male population in Norway. Standardized incidence ratios (SIRs) were used to compare the rates of cancer among the shipyard workers with the national rates obtained through the Cancer Registry of Norway between 1953 and 1995.

The death rate from all causes was lower than expected in the cohort of shipyard workers but the number of deaths from all types of cancer combined was slightly higher than expected (9 observed vs. 7.1 expected; SIR = 1.06, CI = 0.96–1.17). The incidence of lung cancer was non-significantly elevated among welders (SIR = 1.27, CI = 0.58–2.42) and machine shop workers (SIR = 1.70, CI = 0.78–7.33) and was decreased in a sub-cohort of 3001 shipyard workers who had never welded (30 observed vs. 38.1 expected). The difference between the lung cancer incidence in welders and non-welders could not be explained by smoking habits or by asbestos exposure. The relationship between years of welding experience and relative risk of lung cancer is shown in Table 8. The risk was non-significantly elevated among welders with 15 or more years experience (RR = 1.90) but not among welders with 2 to 14 years experience. Welders with less than 2 years experience had the highest lung cancer risk (RR = 2.42) which led to the conclusion that there was not a clear relationship between duration of employment as a welder and lung cancer incidence. In summary, while the risk of lung cancer was elevated in welders, the data were not statistically significant, nor was it possible to discriminate between the effects of mild steel and stainless steel welding. The investigators concluded that a clear relationship between exposure to welding fumes and the development of lung cancer could not be discerned from the current study. These results differed from those they had obtained in an earlier study

Table 8
Relative Risk of Lung Cancer Among Welders Grouped According to Duration of Employment as a Welder at the Shipyard Compared with Other Shipyard Workers (Referents)

	Number of Cases	Relative Risk (RR)	95% Confidence Interval (CI)
Referents	36	1.00	
Welders:			
<2 years	3	2.42	0.73–8.01
2–4 years	1	0.66	0.09–4.85
5–14 years	1	0.56	0.08–4.17
≥15 years	4	1.90	0.67–5.38

Source: Data from Danielsen et al., Ref. 26.

at a different shipyard (Ref. 27) in which the incidence of lung cancer among welders was significantly higher than in the Norwegian male population (SIR = 2.50, CI = 1.14–4.75). The investigators explained that this could have been due, in part, to the recruitment of workers from a rural population in the current study, whereas workers in the earlier study would have come from an urban environment where the overall lung cancer incidence is higher.

In a case-control study designed to evaluate the utility of medical insurance claims records for investigating possible associations between occupational exposures and development of chronic disease, Park (Ref. 106) analyzed data provided by the United Auto Workers (UAW) for workers from eight machining plants of an American automobile manufacturer. The study group included all UAW workers who had been employed in the plants for at least 6 months between 1967 and 1993 and had filed a claim under BlueCross BlueShield from mid-1984 through 1993. The medical claims records included claims for medical insurance payments, together with work histories for the workers involved in the claims. The 12,448 cases considered in the analysis had non-malignant respiratory disease, asthma and allergic alveolitis, coronary heart disease, other heart diseases, and cancer of the lung, pancreas, prostate, or stomach. The controls consisted of equal numbers of workers from the same plants with health insurance claims that were assumed to be non-work-related (e.g., infections and diseases of the endocrine system, circulatory system, digestive tract, and urinary tract).

The results differed substantially from plant to plant, which could not be explained by inter-plant differences in age, gender, or exposures. Dates of disease onset were not available in the claims data base and were estimated from demographic data, date of first claim, and the latency and progressive nature of the disease. When a 25-year latency period was factored into the calculation of odds ratios (OR), welding was significantly associated with an increased risk for lung cancer among those who had begun welding at least 25 years prior to their first claim for lung cancer (OR = 1.73, CI = 1.04–2.89). These data were confounded by various issues including the great variability between the eight participating plants and the finding that the total number of lung cancer cases taken from the medical insurance claims was more than four times greater than that expected from cancer incident rates in the State of Michigan, where half of the plants included in the study were located.

8.2 Kidney Cancer. Renal cell carcinoma (RCC), the most common form of kidney tumor, accounts for about 2% of all malignancies in adults. In a multicenter population-based case-control study, Pesch et al. (Ref. 108) examined associations between RCC and occupational exposures. The study was conducted in five regions of Germany and included 935 cases (570 men and 365 women) diagnosed with renal cell cancer between 1991 and 1995 and 4298 controls (2650 men and 1648 women). Information about occupational history, including job titles and tasks performed, was obtained by interview. Type and extent of exposures were estimated using job exposure matrices. Occupational exposures to lead, cadmium, chlorinated solvents, and soldering fumes were found to be significantly associated with excess risks for RCC. An excess risk was found for men with very long durations of employment in the printing, chemical, and rubber industries. To increase the power of the statistical analyses, some job titles were grouped together and odds ratios determined for the group. The risk of RCC was significantly elevated among women, but not men, with long durations of employment in an occupational grouping that included soldering, welding, and milling. Because welding was not examined independently, no conclusions can be drawn from this study about the risk of RCC among welders.

In 1995, Mandel et al. (Ref. 82) published the results of a multinational case-control study of risk factors for RCC that showed no association between kidney cancer and welding. Hemminki et al. (Ref. 51) used tissues collected from that study to examine the relationship between occupational exposures and mutations in a tumor suppressor gene[10] known to be associated with RCC. Mutations of the von Hipple-Lindau (VHL) tumor suppressor gene have been associated with about 50% of RCCs and are thought to be an initiating step in their development. The type and number of mutations in the VHL gene may vary with environmental or occupational exposures with which RCC is associated. Hemminki et al. (Ref. 51) analyzed the prevalence and patterns of VHL mutations in chromosomes extracted from tissue slices taken from tumors removed from 102 male Swedish patients who had participated in the case-control study of risk factors for RCC conducted by Mandel et al. Mutations in the VHL gene were found in tumor tissue from 47 of the patients with RCC, and tumors from 17 of these patients had two or more mutations. A statistically significant increase in the number of cases with multiple mutations was associated with exposure to welding fumes (OR = 4.7, CI = 1.3–17.0). No other occupational exposures examined in this study (e.g., asbestos, solvents, or petroleum products) showed an increase in the prevalence of mutations. While molecular epidemiology studies of this nature are useful for studying mechanisms and exploring etiologic associations, they are limited in that they may also detect mutations that are not necessarily related to tumor development. The authors noted that while the original study that generated the exposure data and RCC samples did not detect an increased risk for RCC among welders (Ref. 82), a large Nordic cohort study conducted by Andersen et al. (Ref. 5) showed an elevated risk for kidney cancer among Norwegian welders. The findings of this study are also in accord with those of the shipyard study of Puntoni et al. (Ref. 113—see above discussion) which showed a significantly increased risk of death from kidney cancer among the combined group of electric arc welders and gas welders.

8.3 Pancreatic Cancer. Pancreatic cancer is a highly lethal disease whose incidence is rising and cause is largely unknown. Smoking is the only established risk factor for pancreatic cancer but some dietary and chemical exposures have been implicated. To explore possible contributions of occupational exposures to the rising incidence of pancreatic cancer in Spain, Alguacil et al. (Ref. 3) performed a case-control study based on job titles. The 164 (96 men and 68 women) newly diagnosed pancreatic cases and 238 controls (167 men and 71 women) were recruited from five hospitals in Eastern Spain from 1992 to1995. Controls had been initially admitted to the hospital with a diagnosis of potential pancreatic cancer but were found to be free of that disease. They all had other conditions such as chronic or acute pancreatitis or cancer in organs other than the pancreas. Data concerning lifestyle and occupational histories were obtained by interview. About 40% of the male cases had worked as skilled laborers. A statistically significant increase in the risk of pancreatic cancer was observed only for workers who had been employed as physical, chemical, or engineering science technicians (OR = 20.2, CI = 1.8–228). There was a slight, non-significantly elevated risk of pancreatic cancer among workers who had been employed as sheet-metal workers, blacksmiths, welders, structural metal workers, toolmakers, or machine-tool setter-operators (OR = 1.2, CI = 0.4–3.3). The pancreatic cancer risk increased in this occupational group but was still non-significant (OR = 3.3, CI = 0.5–2.1) when the 127 patients with pancreatitis were removed from the control group. When men who had worked for more than 20 years in the trade were excluded, a larger but still statistically non-significant risk (OR = 8.8, CI = 0.9–88) was calculated for pancreatic cancer among men in the occupational group that included metal molders, sheet-metal workers, structural metal workers, welders, and related workers. Because this occupational group included workers in several different trades, it is not possible to draw any conclusions about the risk of pancreatic cancer specific to welders.

8.4 Cancer of the Small Intestine. A series of population-based multi-national case-control studies was conducted in Europe from 1995 through 1997 to explore potential occupational causes of rare cancers of unknown etiology found in seven anatomical sites (small intestine, thymus, bone, gallbladder, male breast, skin, and eye). A common control group with representatives from all of the participating countries was used to establish the incidence of each of these tumor types in the general population. These exploratory studies were designed to identify occupational clustering of these diseases to be used as the basis for future investigations which would more definitively evaluate the association of particular tumor types with specific occupations.

As part of this work, Kaerlev et al. conducted studies which explored occupational associations with two types of rare tumors [small bowel carcinoid tumor (SBC) and small bowel adenocarcinoma (SBA)] found in the small intestine (Refs. 60, 61). The cases in both studies were between 35 and 69 years of age and were recruited from hospitals and by screening of regional and national can-

[10] A tumor suppressor gene is a protective gene that normally restrains cell growth. When a tumor suppressor gene is altered or inactivated by mutation, it may allow uncontrolled cell growth and the development of tumors.

cer registers from Denmark, Sweden, France, Germany, and Italy.

The study of SBC included 2070 controls who were matched to the 84 incident SBC cases by sex, age, and place of residence (Ref. 60). Significantly elevated risks of SBC were found for men employed as shoemakers, structural metal preparers, construction painters, and other construction workers and for women employed in the wholesale food and beverage industry. Welders had a statistically non-significant increased risk of developing this disease (OR = 2.0, CI = 0.8–5.0).

The study of SBA included 79 incident cases, 2070 population controls from the same European countries as the SBC study, and 579 controls diagnosed with adenocarcinoma of the colon recruited from hospitals in Spain (Ref. 61). The risk of SBA was significantly increased among women employed as housekeepers (OR = 2.2, CI = 1.1–4.9), general farm laborers (OR = 4.7, CI = 1.8–12.2), dockers (OR = 2.9, CI = 1.0–8.2), dry cleaners or launderers (OR = 4.1, CI = 1.2–3.6), and textile workers (OR = 2.6, CI = 1.0–6.8). Among men, a significantly increased risk of SBA was found for building caretakers (OR = 6.7, CI = 1.7–26.0) and welders and flame cutters (OR = 2.7, CI = 1.1–6.6). Odds ratios associated with specific welding procedures were obtained by analysis of exposure data obtained from the 12 cases and 384 controls with welding experience who had responded to task-specific supplementary questionnaires. A statistically significant association was found between SBA and GMAW but not GTAW, SMAW, or plasma arc welding (see Table 9). The investigators stressed that, because these studies were exploratory, their findings should be regarded as tentative and in need of further investigation.

8.5 Non-Hodgkin's Lymphoma. Non-Hodgkin's lymphoma (NHL) is among the most rapidly increasing malignancies in developed countries, which suggests that occupational or environmental factors may be, at least in part, responsible for its development. To investigate the contribution of occupational and environmental exposures to NHL, Zheng et al. (Ref. 172) combined and analyzed data from two previously published population-based case-control studies that they had performed to examine the risk of NHL associated with herbicide exposure in Nebraska (Ref. 169) and Kansas (Ref. 56). The Kansas study included 170 male cases diagnosed with NHL between 1979 and 1981. The Nebraska study included 385 cases (201 men and 184 women) of NHL and 56 cases (37 men and 19 women) of a related disease, chronic lymphocytic leukemia (CLL). The cases were matched to 2380 population controls by sex, age, and state of residence. Elementary and high school teachers, farmers and farm operators, and welders and solderers had significantly elevated risks of NHL or CLL. Welders and solderers, had the highest risk (OR = 2.9, CI = 1.2–6.9) of all occupational groups examined. The risk increased with duration of exposure: the odds ratio for men who had worked for 10 or more years as

Table 9
Odds Ratio for Small Bowel Adenocarcinoma According to Selected Welding Exposures

Exposure	Cases (Number)	Control (Number)	Odds Ratio (OR)	95% Confidence Interval (CI)
Welding (12 cases, 384 controls):				
Mild steel welding	9	243	1.6	0.3–7.3
Stainless steel welding	5	172	0.9	0.3–3.0
Degreasing with trichloroethylene	3	92	0.6	0.2–2.6
Oxyacetylene welding	7	222	1.5	0.4–5.5
Oxygen cutting	7	212	1.0	0.3–3.6
Resistance welding	4	135	1.0	0.3–3.5
SMAW	8	226	1.9	0.4–8.3
GTAW	4	50	2.7	0.6–11.7
GMAW	6	94	5.0	1.3–19.6
Plasma arc welding	2	25	3.0	0.5–17.9
Welding environment:				
Close quarters	2	168	0.3	0.1–1.7
Open air (outdoors)	5	139	1.2	0.4–4.3
Small room (workshop)	4	184	0.5	0.1–1.8
Factory hall	9	182	3.7	0.9–15.3

Source: Data from Kaerlev et al., Ref. 61.

welders and solderers was 3.5 (CI = 1.4–8.6). Because the data for welders and solderers were combined, it is not possible to evaluate the risk of NHL among welders from this study. Earlier studies by other investigators [e.g., Persson et al. (Ref. 107), Costantini (Ref. 24), and Andersen et al. (Ref. 5)] have not generally found a significantly increased risk for NHL in welders.

8.6 Cancer of the Eye. While it is rare, ocular melanoma is the most common malignancy of the eye in adults. To examine the role of occupational UV exposure in the development of this disease, Guenel et al. (Ref. 45) conducted a case-control study with 29 male and 21 female patients diagnosed with ocular melanoma in 1995 or 1996 and 470 age- and gender-matched controls from the same geographic area. Occupational exposures were estimated using a job exposure matrix derived from data obtained by interviews. The working hypothesis was that the risk of ocular melanoma is elevated in tradesmen such as welders, sailors, and fishermen who have occupational exposures to UV light.

Light colored skin and eyes were found to be significant risk factors for ocular melanoma. Fishermen, sailors, and others whose occupations involved excessive exposure to solar UV radiation did not have an elevated risk of developing ocular melanoma. In contrast, exposure to artificial UV was a risk factor, and a significantly increased incidence of ocular melanoma (n = 7, OR = 7.3, CI = 2.6–20.) was found in men in the job category of welders and sheet metal workers. The investigators concluded that welders have an elevated risk of ocular melanoma.

8.7 Skin Cancer. The non-melanoma skin cancers (NMSC)—basal cell and squamous cell carcinomas—commonly occur in Caucasians on skin that has had excessive exposure to or damage from the sun and are generally attributed to exposure to UV radiation. Currie and Monk (Ref. 25) noted that 5 of 174 male patients seen consecutively at their clinic with NMSC were welders. Three of the welders were diagnosed with basal cell carcinoma (BCC) and two with squamous cell carcinoma. The lesion was on the face of four of the welders and on the forearm of the fifth. All of the welders had at least 10 years experience in the trade and they had used protective clothing inconsistently. The authors recommended that welders should be encouraged to use protective clothing because exposure to UV radiation from the welding arc can increase the risk of developing basal cell or squamous cell carcinoma.

UVB-induced mutations in two tumor suppressors, the PTCH gene and the p53 gene, have been associated with BCC. Ratner et al. described the case of an 80-year-old retired welder who they had treated for BCC (Ref. 117). Genetic analysis of tumor tissue excised from his sun-exposed skin revealed the presence of two novel mutations in the p53 gene and UV-specific mutations in the PTCH gene. The authors noted that the simultaneous appearance of UV-specific p53 and PTCH mutations in the same BCC sample has not previously been described. They postulated that the patient's exposure to UV from the welding arc contributed significantly to the pathogenesis of his skin tumors.

8.8 Childhood Brain Tumors. Cordier et al. (Ref. 23) performed population-based case-control studies concurrently in seven countries to examine the role of parental occupations in the etiology of childhood brain tumors (CBT). The studies were coordinated by the International Agency for Research on Cancer (IARC) and included 1218 cases and 2223 randomly-selected controls. The cases included children diagnosed with cancer of the brain or cranial nerves between 1976 and 1994. Data concerning occupations held by the parents for at least one month during the 5 years before the child's birth were obtained by interview. A significantly increased risk of CBT was found in children whose fathers worked in agriculture or were electricians, motor-vehicle drivers, or mechanics. Childhood brain tumors were also associated with maternal work in the textile industry. No association was found between CBT and paternal occupation as a welder. The investigators noted that their study did not confirm previous findings by Wilkins and Wellage (Ref. 162) that showed a possible association of CBT with welding.

8.9 Cancer Associated with Electromagnetic Fields. Past studies of the incidence of cancer in welders and other workers exposed to high levels of extremely low frequency electromagnetic fields (ELF-EMF) have yielded inconsistent results. Some have shown an increased risk of leukemia and/or brain cancer in electrical workers, but a link with welding has not been established. Two recent studies examined the cancer risks in electrical workers. The first, by Bethwaite et al. (Ref. 11), was a case-control study of the risks of acute leukemia in electrical workers. The 110 incident leukemia cases were 20 to 75 years old and were recruited from treatment centers in New Zealand between 1989 and 1991. The cases were compared with 199 randomly-selected controls from the general population. Controls were free of leukemia and other blood disorders and were matched to cases by sex, age, and area of residence. The extent of exposure to ELF-EMFs was estimated using a job exposure matrix based upon occupational histories and other data that had been obtained during interviews. Odds ratios for occupational groups with significantly elevated risks for leukemia are shown in Table 10. There was a significantly elevated odds ratio

Table 10
Odds Ratio for Acute Leukemia Cases by Occupation

Occupational Category[a]	Number of Cases (n)	Number of Controls (n)	Odds Ratio (OR)[b]	95% Confidence Interval (CI)
Subjects with no history of electrical work	84	172		
Subjects with any history of electrical work	26	27	1.9	1.0–3.8
Welders/flame cutters	14	9	2.79	1.2–6.8
Telephone line workers	6	2	5.8	1.2–27.8

[a] Only data for occupations with significantly elevated risks are shown.
[b] Odds ratios were adjusted for age, educational attainment, and gender.
Source: Data from Ref. Bethwaite et al., Ref. 11.

for leukemia among workers identified as ever having performed electrical work. The odds ratios for all acute leukemias were significantly elevated for the occupational categories electric arc welders/flame cutters and telephone line workers. Analysis of leukemia risk with duration of job experience indicated a positive exposure/response relationship, which further supports the association. The investigators recognized that their data are not in accord with other studies of the leukemia risk in welders, but they noted that their results are consistent with other investigations that showed a modestly increased leukemia risk among electrical workers other than welders.

Hakansson et al. (Ref. 48) investigated the cancer incidence in a large cohort of resistance welders. Resistance welders were chosen for this study because, while they can be exposed to extremely high levels of ELF-EMF, their exposure to fumes is generally low compared with welders using other welding techniques, which reduces the confounding of the data by exposures other than the ones under study. The study included all employees from Swedish companies likely to use resistance welding in their manufacturing processes (e.g., the automobile industry). All persons ever employed at any of the selected workplaces were identified through income tax returns filed during the period 1985–1994. Information about their jobs was obtained from the Swedish censuses of 1980, 1985, and 1990 and occasionally from work descriptions provided with income tax returns. Exposures were estimated from a job exposure matrix developed from data collected in an earlier study of ELF-EMF exposures by these investigators (Ref. 38). The study cohort comprised 484,643 men and 162,051 women who were divided into four groups (low, medium, high, and very high) according to their estimated exposures to ELF-EMF. About 75% of the subjects in the very high exposure group (>0.530 μt per day) were welders. An unspecified number of women employed in domestic service (low ELF-EMF exposure), as computer operators, and in "other needlework" (high exposure) were added to increase the number of women in the study.

Relative risks for cancer at all sites were determined by comparing the data from the study cohort with those from the Swedish Cancer Registry and Causes of Death Registry. None of the exposure groups showed a significantly increased incidence of leukemia. An increase in brain tumors, with a positive exposure/response trend, was observed in women. A significantly elevated risk for kidney cancer was observed in men in the very high exposure group (n = 62, RR = 1.4, CI = 1.0–2.0). Based on exposure-response relationships, associations were also found between ELF-EMF exposure and cancers of the pituitary gland, bile duct, and liver. It is difficult to discern from the data provided if welding contributed to the increased risk for any of these cancers.

9. Metal Fume Fever

Metal fume fever is a flu-like illness of short duration caused by excessive inhalation of metal oxide particles. Symptoms develop within several hours after exposure and may include chills, fever, muscle or joint pain, difficulty breathing, headache, sore throat and chest tightness. Studies by Blanc and Kuschner et al. (Refs. 12, 75) have indicated that metal fume fever is mediated by cytokines released from macrophages and other leukocytes (white blood cells) following the engulfment of inhaled metal oxide particles. The Norwegian Labor Inspection Authority warned physicians not to treat metal fume fever as a harmless condition because exposures to substances that can cause pulmonary edema may occur simultaneously with the exposure to the metal oxides that causes metal fume fever (Ref. 160). Pulmonary edema may occur hours after inhalation of high concentrations of substances such as nitrous oxides, ozone, and cadmium. A case of a welder with pulmonary edema was described by a physician in Germany (Ref. 140). This condition developed in the evening after welding with no signs of metal fume fever.

Although metal fume fever is most frequently associated with exposure to zinc fumes, it has also been attributed to exposures to other metals. Copper fume is often cited as a cause of metal fume fever, but a report by Borak et al. (Ref. 15) raises questions about this association. Concerned that occupational exposure limits for copper are based on a single report published in 1968 by Gleason (Ref. 42), Borak et al. searched the international literature to evaluate whether there is sufficient evidence in humans to support an association between metal fume fever and exposure to copper fumes or dust. They found that seven relevant papers had been published over an 88-year period.

None of these papers reported cases that involved welding or brazing of copper, and only one involved thermal cutting of copper. Borak et al. found Gleason's report of an acute upper respiratory illness in workers polishing copper plate to be inadequate proof that copper causes metal fume fever because the affected workers lacked symptoms typical of this condition and did not develop tolerance following repeated exposures. In three of the seven reports (including that of Gleason), exposures were to mixtures of two or three metals, and copper could not be isolated as the cause of the symptoms. In two of the reports, the working conditions did not vary from day to day and the symptoms could have resulted from unknown contaminants. Borak et al. found the associations in the remaining two reports to be suspect because the exposures were not to freshly formed fumes and, in one case, fume particles were measured and were greater than 1 μm in diameter. The authors concluded that, because of the extensive industrial uses of copper and the small number of reported cases, if metal fume fever does result from exposure to copper fumes, it must be very rare.

A typical case of metal fume fever was described by Merchant and Webby in Sydney, Australia (Ref. 91). A 26-year-old man reported to the emergency room with fever, chills, headache, muscle pain, nausea, and breathlessness 4 hours after oxygen cutting galvanized steel in a confined space without the benefit of respiratory protection. Blood cell counts showed leukocytosis (an elevated number of circulating white blood cells) which is frequently observed during metal fume fever. The patient was treated for his symptoms and released from the hospital symptom-free 10 hours later. This man had experienced metal fume fever on previous occasions after working under similar conditions.

In another incident, a 55-year-old plumber who had been disassembling a steel tank with an oxyacetylene torch, and his 18-year-old son who had been assisting him, reported to the emergency room in Bristol, England (Ref. 66). The father was more severely affected than was the son. He experienced malaise, fatigue, cough, fever, nausea, and difficulty breathing. Clinical examination indicated leukocytosis. His son suffered from malaise, nausea, vomiting, and cough. Both were fully recovered by the next morning.

Ebran et al. (Ref. 34) described the case of a 32-year-old French welder who developed metal fume fever 3 hours after exposure to zinc fumes. His symptoms included cough, fever, muscle pain, and chills. Clinical examination revealed leukocytosis and chest X-rays revealed bilateral diffuse infiltrative pulmonary lesions. Ebran et al. noted that the last finding is rarely associated with metal fume fever.

A fourth incident of metal fume fever was reported by Fuortes and Schenck (Ref. 41) in the U.S.A. In this case, a 33-year-old welder presented with a high fever, malaise, chills, muscle and joint pain, severe chest pain, and a persistent productive cough. He had experienced similar, but much less severe, symptoms several times during the preceding 2 months during which he welded galvanized steel exclusively throughout the work shift. Clinical examination revealed leukocytosis and a high concentration of urinary zinc (138 mg/Dl). A pleural friction rub[11] was heard during examination of his chest with a stethoscope. The welder returned to work in an area where galvanized steel was not welded. He suffered no further problems and the pleural rub was no longer apparent 2 months later. The authors noted that pleural friction rub had not previously been associated with metal fume fever. They concluded that the pleural rub was most likely related to the high exposures to zinc that this welder experienced continually over a 2-month period.

10. Effects on the Ear

Burns of the outer ear and ear canal, and perforation of the tympanic membrane (eardrum) are among the most frequently encountered ear injuries in welders. Five

[11] A pleural friction rub is a squeaky, rubbing sound heard through a stethoscope when the membranes from the lungs and chest cavity rub against each other as the lungs expand and contract. This occurs when the pleural membranes surrounding the lungs are thickened, roughened, or irritated.

cases of welding spark injuries of the middle ear were described by Kupisz et al. (Ref. 74). The patients, aged 41 to 52 years, were all injured while welding. They were treated during a 2-year period at hospitals in Lublin, Poland. Three of the patients had sought medical help within 2 months of their injury and the other two patients waited 4 years before seeking medical assistance. At the time of their initial examination, all of them complained of hearing loss, two were experiencing tinnitus, and two had vertigo. The tympanic membrane was injured in all five cases. All of the patients were treated surgically during which metal filings could be removed from the ears of four of them. The three patients who sought medical help within the first 2 months after injury showed hearing improvement within 3 months after treatment. The long-lasting presence of a metal filing in the middle ear spaces of the remaining two patients led to a chronic inflammatory process with progressive hearing loss. Neither of these patients showed improvement at 3 months after treatment. Kupisz et al. stressed that persons sustaining a middle ear injury caused by a welding spark should have surgical treatment within, at most, 2 to 3 months after the injury because the expeditious removal of a foreign body from the middle ear spaces improves the results of surgery and the chances for regaining hearing.

11. Effects on the Eye and Vision

11.1 Eye Injuries. Welch et al. (Ref. 159) analyzed the incidence of eye injuries among construction workers treated in the emergency department of a hospital in Washington, D.C. over a period of 8 years. During that time, 3390 injured construction workers, 36 of whom were welders, reported to the emergency room; 363 (11%) of the construction workers had suffered injuries to the eye. Welders had the highest rate of eye injuries (30.1%), followed by plumbers (18%), painters/glaziers (15%), and insulators (15%). The investigators interviewed 62 of the construction workers with eye injuries and found that while many of them routinely wore eye protection, most did not use eye protection with top and side shields. They concluded that up to two thirds of the eye injuries among the construction workers could have been prevented by the use of goggles or full shields, but these data were not specifically analyzed for welders.

Using the Defense Medical Surveillance System, Andreotti et al. (Ref. 6) surveyed the incidence of hospitalizations and ambulatory visits for eye injuries among all persons who served in the U.S. Armed Forces during the year 1998. Approximately 1% of the study population of 1.6 million active duty military personnel was treated for eye injuries in 1998. The ambulatory incidence rates for eye injuries were three to four times higher among workers in the occupations classified as metal body repair (4%), welding (3.7%), metal working (3.2%), and machinists (2.1%) than among the study population as a whole.

Okoye and Umeh (Ref. 102) conducted a survey of eye injuries among 646 workers in four factories, a cement factory, coal mine, saw mill, and iron/steel works, in Nigeria. Of these workers, 184 (28.5%) had received work-related injuries, of which 81 (12.5%) affected the eye. Eighteen workers had received more than one eye injury. The distribution of eye injuries was similar throughout the four plants surveyed. "Welding arc rays" were listed among the most common sources of injury and were responsible for 12.6% of the injuries that occurred in the plants surveyed. Eye protection was most frequently used by workers in the iron/steel plant where 46% used protective gear. None wore eye protection in the sawmill. The authors stated that legislation should be passed and vigorously enforced to promote the use of eye protection in order to reduce the frequency of eye injuries in factories in Nigeria.

11.2 Visual Acuity. Boissin et al. (Ref. 14) compared the visual acuity of 850 welders with that of 281 controls who worked in twelve large factories in France. Data were collected by the occupational physicians employed by these plants. About 70% of the welders were involved with welding activities for more than 75% of the workday. The incidence of hyperopia (farsightedness) was similar between welders and controls but the vision of welders was less frequently corrected for myopia (nearsightedness). Optical correction for myopia was more common among welders who used SMAW than among those who used GMAW or GTAW. This finding was unexpected and could not be explained by the authors.

The only test in which controls fared better than welders was the vision recovery time after exposure to glare, but the difference was not significant. The average recovery time was 20 seconds among controls and 30 seconds among the welders. No difference in recovery time was observed between welders who used GTAW and controls. The incidences of night and color blindness did not differ between welders and controls. The vision of each subject was tested at the start of the study and again one year later and no changes in visual functions were observed during that time. In summary, the study revealed no significant effects of welding on visual acuity, which the authors attributed to the protective and preventive eye care measures used by the companies that participated in the study.

11.3 Retina. In Italy, Magnavita (Ref. 81) described a case of welding arc maculopathy in a 45-year-old millwright who had welded for more than 25 years. During his career, he had primarily used GMAW, submerged arc welding, and oxygen lance cutting. In 1996, he experienced acute eye pain while welding. In the following days, he developed a scotoma which appeared as a persistent bright spot in the center of his vision. He also reported having blurred vision and photophobia. Ophthalmoscopic examination of the retina showed a bright yellow edematous lesion in the fovea[12] of each eye. Reexamination 4 years later showed persistent retinal lesions and a loss of visual acuity in both eyes. The visual impairment had interfered with the welder's work and he was forced to leave his job. He was denied worker compensation for permanent disability because an association between exposure to the welding arc and retinal injuries was not acknowledged by Italian authorities. Magnavita cited published reports indicating that severe burns of the retina caused by radiation from the welding arc can cause permanent partial or complete loss of central vision (Refs. 19, 37, 151) and argued that workers with retinal damage resulting from exposure to the welding arc should be eligible for disability insurance.

Mauget-Faysse et al. (Ref. 88) reported the case of a 73-year-old man who developed a central scotoma, and blurred and distorted vision in his left eye after inadvertent exposure to an electric welding arc that was approximately 3 meters from the left side of his body. Ophthalmologic examination revealed lesions on the macula of his left eye. Exposure to the arc was deemed to have been insufficient to have caused these lesions under normal circumstances and his retinal burn was attributed to his use of the diuretic quinapril for hypertension and allopurinol for hyperurecemia at the time of his exposure. Both drugs are photosensitizers. His symptoms gradually improved and his vision returned to normal within a year.

In 1991, Power et al. (Ref. 111) attributed the development of maculopathy in a welder to the use of the photosensitizing drug fluphenazine. In addition, photosensitizing drugs have more recently been associated with allergic photodermatitis in a welder (Ref. 154, see section 11.0—Effects on the Skin). Thus, it is important that welders who are taking medications known or suspected to be photosensitizers use extra precautions against exposure to UV radiation when welding.

11.4 Cornea. While exposure of the eye to UV radiation is an established cause of photokeratitis, a temporary condition which affects the outer surface of the cornea, damage to corneal endothelium resulting from radiation from the welding arc has not been reported. The corneal endothelium is a monolayer of multisided cells that lines the innermost surface of the cornea and is essential for maintenance of its integrity. Corneal endothelial cells do not divide, so if a cell is damaged or destroyed, other cells enlarge and change shape as they fill in the space once occupied by the damaged cells. To determine whether welding exposures affect the corneal endothelium, Oblak and Doughty (Ref. 100) examined the corneas of 20 welders and 20 office workers. The size and shape of the corneal endothelial cells were determined using photo-micrographs of the corneal endothelium taken from each subject. The average age of the welders and controls was 46 years and 48 years, respectively, and the welders had an average of 25 years experience. All the welders reported having experienced photokeratitis up to 3 times per year, which confirmed that they had experienced occupational exposures to UV radiation. Despite these exposures, the corneas of all the welders appeared to be healthy. The curvature and thickness of the cornea, and the size or shape of the corneal endothelial cells did not differ substantially between welders and controls. Oblak and Doughty concluded that, despite the evidence that welders in this study had received repeated UV exposures strong enough to cause multiple incidents of photokeratitis, the doses received were not sufficient to damage the deeper lying corneal endothelium.

12. Effects on the Skin

Using the West Virginia Workers' Compensation database, Islam et al. (Ref. 59) examined the incidence rates of work-related burn injuries that occurred during a period of 1 year. Of the 64,646 claims for work-related injuries or illnesses filed during this time, 1600 claims for burn injuries were approved for compensation. The annual incidence rate of all work-related burn injuries was 26.4 per 100,000 workers in the entire West Virginia workforce. Burns to the eye accounted for the greatest proportion of burn injuries among male workers. The primary causes for eye burns were chemicals and hot liquids. Welders had the highest incidence rate for all burn injuries excluding those of the eye (140.3 per 100,000 workers), followed by cooks (138.7 per 100,000), laborers (45.1 per 100,000), and food service workers (39.2 per 100,000). Welders also had the highest incident rate of third degree burns (7.4 per 100,000), followed by laborers (4.1 per 100,000) and cooks (1.2 per 100,000).

Lack and Weingold (Refs. 76, 77) described a patient who had been referred to their dermatology practice with a painful, ulcerated wound from a welding slag burn on the back of the hand. The ulcerated wound had previously been diagnosed by another physician as a bacterial

[12] The fovea is an area in the center of the macula that is essential for vision.

infection and had been treated unsuccessfully with antibiotics. The authors diagnosed the condition as a form of “Sweet’s syndrome” (acute neutrophilic dermatitis) after biopsy revealed that the wound was infiltrated with neutrophils or polymorphonuclear leukocytes (PMNs). The patient experienced a rapid recovery after treatment with corticosteroids, and the authors cautioned that not all wounds of this nature should be treated as bacterial infections.

In another case, lichen sclerosus et atrophicus (LSA), an inflammatory skin disorder, was diagnosed by Tegner and Vrana (Ref. 147) in a 46-year-old sheet metal worker. White, firm, round, indurated plaques typical of LSA had developed in many of his old scars from burns caused by welding sparks. The plaques appeared primarily on his chest, shoulders, and arms in spots where his skin had been burnt by sparks that had burned through his clothes. LSA was confirmed by pathology of biopsied tissue.

Munnoch et al. (Ref. 96) used laser therapy to treat spider naevi[13] on the cheeks of a 24-year-old man. Following the treatment, the patient was instructed to use factor 25 sunscreen because exposure to the sun could cause pigmentation of the treated area of the skin. Despite his use of a sunscreen, his cheeks became severely hyperpigmented within 6 weeks. At that time, the physicians learned that the patient was a welder and that he used GMAW exclusively. They attributed the hyperpigmentation to the high levels of UVC radiation (wavelengths of 100 nm–280 nm) that are generated by GMAW and explained that sunscreens provide protection against UVA (315 nm–400 nm) and UVB (280 nm–315 nm), but not against UVC.

Wagner et al. (Ref. 154) described the case of a welder who developed erythema and burning of his face after welding. The skin lesions gradually worsened and he developed eczema on his face, neck, and forearms. He experienced an intense burning sensation following exposure to sunlight and while welding, even though he used a sunscreen and wore goggles and a welding shield while welding. He ceased welding 2 years after developing these problems. The more severe symptoms resolved, but he continued to experience mild eczema on his face and neck. He sought treatment for this continuing condition from a dermatologist who found that he had developed photo-allergies to the two medications, hydrochlorothiazide and ramipril, that he had been taking for hypertension. He had begun using these medications about 9 months before he began to experience skin reactions to welding and sunlight. Both drugs caused strong positive reactions in photopatch tests following irradiation with UVA but not with UVB or visible light. A change in his medication to a different anti-hypertensive drug and treatment with topical corticosteroids led to a complete resolution of his skin problems.

Markandeya and Shenoi (Ref. 83) described the case of a 42-year-old welder with persistent hyperpigmentation over both forearms. The symptoms had first appeared as erythema after his first month of welding and then became more pronounced over the next 8 years, during which he had been engaged in arc welding for 3 hours to 4 hours per day. He had not worn protective clothing while welding. His condition improved considerably when he was treated with topical sunscreens, emollients, and topical hydroquinone.

12.1 Systemic Sclerosis. Systemic sclerosis (SSc or scleroderma) is a systemic disorder in which fibrous connective tissue becomes deposited in the skin, lungs, other internal organs, and small arteries. The disease is four times more common in women than in men. While its etiology is not understood, exposures to silica, certain organic solvents, and to equipment that causes hand-arm vibrations are suspected risk factors. To investigate the role of occupational exposures in the development of SSc, Diot et al. (Ref. 33) conducted a case-control study with 80 patients (69 women, 11 men) admitted consecutively from 1998–2000 to the University Hospital of Tours, France. The 160 controls were patients who were admitted during the same period with other chronic diseases. Two controls were matched to each case based on age, gender, and smoking habits. Data concerning occupational histories and exposures were obtained by interview.

The occupational exposures experienced by the study population that were significantly associated with SSc are shown in Table 11. Significant associations were observed for crystalline silica, various solvents, epoxy resins, and welding fumes. A significantly increased risk for SSc (OR = 3.74, CI = 1.06 to 13.18, 7 cases, 4 controls) was observed among persons who had ever been occupationally exposed to welding fumes. When the analysis was restricted to those with high cumulative welding fume exposures (6 cases, 2 controls), the risk was increased (OR = 6.41, CI = 1.26–32.49). The authors noted that exposure to welding fumes occurred simultaneously with exposure to silica in six of the eleven subjects with SSc, making it difficult to discern between the effects of the two exposures and weakening the argument for an association between SSc and welding fumes.

[13] Spider naevi or spider veins are networks of small, thin, dilated blood vessels that lie close to the skin’s surface. They may be red, blue, or purple.

Table 11
Risk Associated with Occupational Exposure Among 80 Cases of Systemic Sclerosis and 160 Matched Controls

Exposure[a]	Cases (n)	Controls (n)	Odds Ratio (OR)	95% Confidence Interval (CI)
Crystalline silica	10	4	5.57	(1.69 to 18.37)**
Trichlorethylene	13	12	2.39	(1.04 to 5.22)*
Chlorinated solvents	16	14	2.61	(1.20 to 5.66)*
Toluene	8	5	3.44	(1.09 to 10.90)*
Aromatic solvents	11	9	2.67	(1.06 to 6.75)*
Ketones	8	2	8.78	(1.82 to 42.38)**
White spirit	15	10	3.46	(1.48 to 8.11)**
Any type of solvent	22	20	2.66	(1.35 to 5.23)*
Epoxy resin	6	3	4.24	(1.03 to 17.44)*
Welding fumes	7	4	3.74	(1.06 to 13.18)*

[a] Ever versus never exposed; *$p < 0.05$; **$p < 0.01$.

Source: Data from Diot et al., Ref. 33.

13. Effects on the Nervous System

13.1 Effects of Aluminum. Riihimaki et al. (Ref. 119) examined the relationship between central nervous system function and aluminum concentrations in serum and urine in 59 welders who exclusively performed GMAW of aluminum. The subjects and 25 mild steel welders who served as referents were employed by eight companies in Finland. Data concerning occupational history, general health, and nervous system symptoms were obtained by interview. Based on the median concentrations of aluminum in their urine and serum, the subjects were divided into three groups: no exposure (25 mild steel welders), low exposure (29 aluminum welders), and high exposures (30 aluminum welders). The median concentrations of aluminum were 0.4 µmol/L, 1.8 µmol/L, and 7.1 µmol/L urine and 0.08 µmol/L, 0.14 µmol/L, and 0.46 µmol/L serum for the no, low, and high exposure groups, respectively. A neuropsychological test battery, symptom and mood questionnaires, and electroencephalograms (EEGs) were administered to assess central nervous system function.

Significant differences ($p > 0.05$) were seen between the high exposure group and the referents in the self-reported symptoms of fatigue, emotional lability, memory loss, and difficulties in concentration. These symptoms were found to be highly associated with the duration of exposure. Neuropsychological test batteries which measured performance in tasks that required complex attention, the processing of information in the working memory system, and in the analysis and recall of abstract visual patterns showed significant differences between the high exposure group and referents. Mild to moderate EEG abnormalities were found in aluminum welders but not controls. The percent of individuals with abnormalities was higher in the high-exposure group than in the low exposure group. Based on these data, the investigators estimated that aluminum concentrations of 4 µmol/L–6 µmol/L in urine and 0.25 µmol/L–0.35 µmol/L in serum represent the threshold for multiple adverse effects in aluminum welders.

Bast-Pettersen et al. (Ref. 10) examined neurobehavioral/neuromotor function in 20 aluminum welders who worked at a Norwegian railroad wagon production factory. Tremor, reaction time, and self-reported neuropsychiatric symptoms were compared between the aluminum welders and an equal number of age-matched construction workers employed at a nearby facility. The welders had an average 8.1 years of exposure to aluminum and their mean and median urinary aluminum concentrations were 1.86 µmol/L and 1.5 µmol/L, respectively. Aluminum concentrations in air samples collected inside the respirator were used to quantify aluminum exposures during the study. The mean concentration was 1.18 mg/m^3. The welders were involved with GMAW of aluminum for 50% of the work shift.

Self-administered questionnaires were used to assess neurological symptoms and difficulties with memory and concentration. Welders reported significantly more neurological symptoms than did controls, but the incidence of subjective symptoms was lower than expected based on clinical standards. Hand steadiness was measured using an apparatus in which the subject inserted a stylus into successively smaller holes without touching the sides of the holes. The welders, as a group, performed significantly better than did the construction workers in this test. However, when the results among the welders were analyzed separately, a significant positive correlation was found between the duration of the welding experience and hand steadiness. The results of the steadiness test did not correlate with aluminum concentrations in urine or breathing zone air samples. Neither of the groups showed clinically significant signs of tremor, and computerized tests of reaction times in both welders and controls were considered to be good compared with clinical standards. Among the welders alone, there was a significant relationship between the reaction times and the concentration of aluminum in the breathing zone air samples. The investigators concluded that while the results of the neurobehavioral tests did not show an effect of aluminum exposure, the correlations between extent and duration of aluminum exposures and hand steadiness, and between reaction time and breathing zone concentrations of aluminum, might indicate slight effects from aluminum exposure. The median urinary aluminum concentrations were similar in welders from this study and in the low-dose group from the study of Riihimaki et al. (Ref. 119). Only minimal central nervous system effects were seen in either group of welders.

13.2 Effects of Manganese. In 2001, Racette et al. published the results of a study on the clinical features of welding-related parkinsonism (Ref. 116—see discussion in Effects of Welding on Health, Volume 12). In that study, he compared the symptoms and disease course in fifteen welders with parkinsonism with that of two set of controls with idiopathic Parkinson's disease. Based on their findings that the clinical symptoms were similar between the welders and controls and that the age of onset was the only difference between the two groups, they concluded that welding may be a risk factor for parkinsonism that accelerates the progression of the disease. In response to this report, Sadek and Schulz (Ref. 122) pointed out that manganism may differ from idiopathic Parkinson's disease in several ways, especially in the early stages of the disease, and that at later stages the two conditions may be indistinguishable. They argued that some or all of the welders in the study of Racette et al. may actually have had manganism and not idiopathic Parkinson's disease. That manganism may have been responsible for the parkinsonism observed in welders by Racette was also suggested by Frucht (Ref. 40). In a Letter to the Editor, Ravina (Ref. 118) noted that 53% of the welders in the Racette study had a family history of Parkinson's disease compared with 32% of the controls, suggesting an alternative mechanism for the early age of onset. Racette (Ref. 115) responded that the "high frequency of positive family history in welders warrants additional studies to determine if there is a common genetic etiology in these subjects" and that a "proper epidemiologic study" will be necessary to prove the relationship between welding and parkinsonism. Finally, in their comments concerning the study of Racette et al., Pezzoli et al. (Ref. 109) noted that in an earlier study they showed that Parkinson's disease patients who had a history of occupational exposure to hydrocarbon solvents had an earlier onset of the disease**,** which led them to conclude, as had Racette, that an environmental factor accelerates the onset of parkinsonism. In addition, Pezzoli et al. had found that the disease was more severe throughout its course in patients with a history of hydrocarbon exposures. Pezzoli et al. suggested that a similar phenomenon may not have been seen by Racette et al. because they used a less sensitive method to estimate disease severity.

McDonnell et al. (Ref. 89) searched the national pension fund archive of death certificates and occupational records for employees from a major British automobile manufacturer to examine the association of Parkinson's disease with exposure to metals or solvents. Among the 20,256 death certificates examined, 182 were identified in which Parkinson's disease was noted. The cases in the study were the 57 males identified by death certificate as having had Parkinson's disease for whom occupational records could be found. The 206 controls were men randomly-selected from the same data bases as the cases for whom full occupational records could be found. The risk for Parkinson's disease was non-significantly elevated among those who had been exposed to solvents (OR = 1.53, CI = 0.81–2.87) or metals (OR = 1.55, CI = 0.78–3.09). There was a significant association between Parkinson's disease and more than 30 years exposure to solvents, with an odds ratio of 3.59 (CI = 1.26–10.26) The risk for Parkinson's disease was not associated with the duration of exposure to metals.

Sinczuk-Walczak et al. compared nervous system function in 75 manganese-exposed Polish workers (62 shipyard welders and fitters and 13 battery production workers) with that in 62 non-exposed age-matched controls (Refs. 133, 134). The mean age of the exposed workers was 39 years (range: 20 to 56 years) and they had been employed for a mean of 17.5 years (range: 1 to 41 years). Neurological examinations were administered to each subject. Current manganese exposures were measured in the breathing zones of each exposed worker for a full work shift. The Polish MAC for manganese of 0.3 mg/m^3 was exceeded in samples collected in the areas where six of the battery production workers and 30 of the welders worked. Breathing zone manganese concentrations measured during welding ranged from 0.004 mg/m^3 to 2.67 mg/m^3 (mean: 0.4 mg/m^3). For battery workers, the mean manganese concentration was 0.338 mg/m^3 and the range was 0.09 mg/m^3–1.16 mg/m^3.

The manganese-exposed workers reported emotional irritability, impaired memory, difficulty concentrating, sleepiness, and paresthesia (abnormal spontaneous tingling or burning sensations) in the extremities significantly more often than did controls. However, the frequency of occurrence of these symptoms was not significantly related to the manganese exposures measured during the study period or to the cumulative exposure index (the product of the current exposure and the total exposure duration in years). Neurological examination did not reveal peripheral or central nervous system changes indicative of clinical encephalopathy or neuropathy. Abnormal electroencephalograms were found more frequently in exposed workers than in controls but the differences between the two groups were not significant. Tests of visual evoked potential revealed abnormalities that could be indicative of subclinical optic nerve disorders. These findings were significantly related to the cumulative exposure index. The investigators concluded that manganese exposures at or slightly above the MAC value may cause subclinical effects on the nervous system.

Ono et al. (Ref. 105) described the case of a 17-year-old Japanese man who had myoclonic involuntary movements characterized by sudden brief, jerky, shock-like movements of his right arm and leg that were attributed to manganese poisoning. The patient had been employed in arc welding for about 2 years in a plant described as having used manganese. His symptoms first appeared as trembling of his right arm and leg while he was welding. He was admitted to the hospital 2 months after onset of the trembling. Manganese concentrations in his blood were found to be elevated but concentrations of iron, lead, copper, and arsenic were within normal ranges. Magnetic resonance imaging of the brain revealed signals typical of manganese exposure. Chelation therapy for 5 days resulted in urinary excretion of high levels of manganese. At the end of the therapy, the manganese concentration in blood was within the normal range and the myoclonic involuntary movements of his extremities was markedly reduced. Within 3 months after chelation therapy, the high-intensity signal on T1-weighted magnetic resonance images had completely disappeared, indicating that the manganese had been cleared from the brain.

14. Effects on the Cardiovascular System

Sjogren et al. (Ref. 135) compared mortality rates from ischemic heart disease[14] (IHD) among male welders with that of the entire population of actively working men in Sweden. Two cohorts of welders were studied. The first comprised the 31,722 welders identified in the 1970 Swedish National Census; the second group comprised the 28,068 welders identified in the 1990 census. Deaths from IHD were followed in both cohorts until 1995 and in the approximately 4,000,000 gainfully employed controls identified in the same census records. An actively working control population was used in this study to reduce the potential bias that can be introduced by the healthy worker effect in which the control population may be overweighted with people who are too ill or disabled to continue working.

A small but significant increase in the mortality from IHD was observed among welders in both the 1970 (SMR = 1.06) and 1990 (SMR = 1.35) census groups (see Table 12). To estimate the contribution of smoking

[14] In ischemic heart disease, also known as coronary artery disease, blood vessels leading to the heart are narrowed or blocked, restricting blood flow to the heart. The resultant decrease in oxygen (ischemia) can damage heart muscle. Complete blockage of a blood vessel leads to a myocardial infarction.

Table 12
Standardized Mortality Ratios (SMR) of IHD in Two Cohorts of Welders and Gas Cutters Followed until the End of 1995

Cohort	Number of Welders[a]	Number of Referents	Cases Observed	Cases Expected	SMR	Confidence Interval (CI)
1970 Census	31,722	2,047,861	2156	2028.9	1.06	1.02–1.11
1990 Census	28,068	2,163,967	102	75.3	1.35	1.10–1.64

[a] The number of welders in the census records was thought to have decreased from 1970 to 1990 due to refinements in data retrieval.

Source: Data from Sjogren et al., Ref. 135.

to the excess risk values for IHD, the investigators surveyed smoking habits among a population of 8474 men, 112 of whom were welders, between 1986 and 1990. They determined that smoking among welders was sufficient to have caused the increased risk of IHD in the 1970 cohort but not in the 1990 cohort. They reiterated the hypothesis first posed by Seaton (Ref. 126) that inhalation of airborne particulate may increase the risk of cardiovascular disease by causing the release of mediators such as Interleukin-6 (IL-6) which can influence the secretion of fibrinogen, thereby increasing the propensity for blood clots to form.

Sjogren et al. suggested that, just as past smokers have a lower mortality from IHD than do current smokers, workers with current exposure to welding fumes may have a greater risk of IHD than do retired welders. Thus, the cohort of men from the 1970 census, which was followed for 25 years, may have been over-weighted with retired welders who no longer had an increased risk for IHD. The 1990 cohort was only followed for 5 years and a larger percent of the welder population would have been actively welding and at greater risk for IHD from welding fume exposures throughout the study period.

Suadicani et al. (Ref. 142) conducted a study to test the hypothesis developed in earlier work (Ref. 143) that men with type O blood are more susceptible to cardiovascular effects from occupational exposures to airborne particulate than are men with other blood types. The study began in 1985 and included 3321 of the participants from an earlier Danish prospective cardiovascular cohort study that had included 5249 men with a mean age of 48 years in 1970. None of the participants in the new study had experienced any signs of cardiovascular diseases or symptoms. Venous blood samples to be used for ABO blood typing were obtained from all participants. An 8-year follow-up was conducted during which mortality and morbidity data were obtained from the Danish Central Person Register.

The study group contained 1417 men with the O blood group phenotype and 1904 men with other phenotypes. At the end of the follow-up, in 1993, 4.7% of the men with no previously-reported heart disease who were of phenotype O had myocardial infarctions (MIs), compared with 5.7% of those with other phenotypes, demonstrating that, in the absence of exacerbating factors, men with type O blood do not have an increased risk for cardiovascular disease. Odds ratios for MI were calculated from work history data by comparing men with a long-term exposure (greater than 5 years, several times per week) to various occupational pollutants with those who did not meet the long-term criteria. The incidence of MIs was significantly increased in men with type O blood who had long term exposure to fumes from soldering (OR = 3.0, CI = 1.6–5.8), welding (OR = 2.1, CI = 1.05–4.3), and plastics (OR = 8.3, CI = 2.6–27.0). In men with phenotype other than O, no significant increases in the incidence of MIs were associated with any of the pollutants tested. Although there was a strong association between smoking and the incidence of MIs, there was no apparent interaction between smoking and possession of phenotype O, suggesting that smoking and environmental pollutants may increase the risk of heart disease by different biological pathways.

15. Hand-Arm Vibration Syndrome

Excessive exposure to equipment that causes hand-arm vibration can result in both neurological (tingling and numbness in the hands) and vascular (Reynaud's phenomenon or vibration white finger) damage referred to as hand-arm vibration syndrome (HAVS). This condition develops gradually and increases in severity over time with continued exposure. McGeoch and Gilmour (Ref. 90) conducted a study at a Scottish engineering company to examine how different trades are affected by the hazards from vibrating tools. The study included 165 men (74 welders, 58 fitters, 17 platers, and 16 dressers) who had worked with vibratory tools for an average of 23.3 years. The welders used pneumatic grinders and pneumatic chipping hammers. The remaining subjects used only pneumatic grinders at the time of the study, although most of the dressers had previously used caulking hammers as well. Questionnaires were administrated to all subjects to document their experience with vibratory tools and their histories of vascular and neurological signs and symptoms related to HAVS. A battery of tests was administered to each participant to diagnose and rate the severity of HAVS. Daily exposure measurements during a 3-week period at the start of the study were used in conjunction with years worked at the plant to estimate lifetime exposure to vibration.

Symptoms of HAVS were seen in 63% of the subjects. Neurological symptoms were more prevalent than vascular symptoms: 53 subjects (32%) had both neurological and vascular symptoms, 49 subjects (30%) had neurological symptoms only, and 2 (1%) had vascular symptoms only. Neurological and vascular symptoms were both significantly associated with age and total hours of exposure to vibration; neither was associated with smoking. Years of tool use was the most significant factor associated with neurological damage; years of tool use and trade were the most significant factors associated with vascular damage. Dressers were the tradesmen most likely to have vascular symptoms.

The mean latent period (time from beginning of exposure to first appearance of symptoms) was 19.7 years for the onset of neurological symptoms and 19.1 years for the onset of vascular symptoms for all the subjects. The latent periods for both neurological and vascular symptoms were significantly shorter for welders and dressers than for fitters and platers. Welders had the shortest latent period of all trades examined, with mean latencies for both sets of symptoms of about 15 years.

Differences among the trades were attributed to the hours of exposure and equipment used. The short latent period experienced by the welders was attributed to their use of pneumatic chipping hammers, which have higher acceleration and cause more damage than pneumatic grinders. The short latent period experienced by the dressers was attributed to their long hours of exposure to vibration equipment.

16. Effects on the Endocrine System

Thyroid function is routinely examined in the clinic by measuring circulating levels of thyroxin and thyroid stimulating hormone (TSH or thyrotropin). Thyroxin, a hormone that regulates the rate of cellular metabolism, is produced by the thyroid gland and has two forms—T3 and T4—depending on whether it has 3 or 4 attached iodine atoms. If circulating levels of thyroxin are low, the pituitary gland releases TSH which, in turn, stimulates the thyroid to manufacture and secrete more T3 and T4. In a pilot study of thyroid function, Zaidi et al. (Ref. 170) compared the concentrations of the hormones TSH, T3, and T4 in the serum of 20 men who had been employed as welders for an average of 13.5 years with those of 20 men whose occupations had involved no welding or chemical exposures.

The average concentrations of T3 and T4 did not differ between the welders and controls. However, the concentrations of TSH were elevated in serum from four of the welders, which caused the average concentration of TSH to be significantly increased ($p < 0.02$) in welders compared with non-welders. None of these four welders had clinical signs of thyroid disorders. The investigators concluded that the welders with elevated TSH levels had indications of possible sub-clinical hypothyroidism that may have been due to their working environment. But they noted that the elevated TSH could also have resulted from some non-thyroidal conditions which could not be ruled out without further study.

17. Effects on the Immune System

Polymorphonuclear leukocytes are phagocytic white blood cells that play an important role in the primary immune response against bacteria and in the removal of cellular debris from the body. They normally circulate in the blood and migrate into sites of inflammation where they may represent the major inflammatory cell type. As part of their antibacterial function, they release the highly reactive superoxide anion when appropriately stimulated. Aloufy et al. (Ref. 4) investigated PMN function in 23 Israeli arc welders by measuring superoxide production by PMNs isolated from their peripheral blood. The results in welders were compared with those in 23 age- and smoking habit-matched office workers. Isolated PMNs were stimulated *in vitro* by treatment with phorbol myristate acetate and the release of superoxide anions was measured. Significantly less ($p = 0.021$) superoxide was released from stimulated PMNs obtained from welders than from those obtained from controls. The release of superoxide anions from stimulated PMNs was non-significantly lower in smokers than in non-smokers among both welders and controls. The authors concluded that PMN function is reduced in welders. They suggested that the effect of welding on PMNs may be related to the inhalation of oxidant gases such as ozone and nitric oxide and that the function of PMNs obtained from peripheral blood could serve as a biological marker of exposure during periodic health examinations of welders.

Ayatollahi (Ref. 9) examined serum immunoglobulin levels in 66 workers with heavy exposures to lead in Iran. The levels of the immunoglobulins IgG, IgM, and IgA were measured in 21 battery shop workers, 12 welders of car radiators and exhausts, 21 print shop workers, and 12 car painters. Welders had the highest mean blood lead level (mean BLL: 59.4 g/dl) among all the groups of workers (overall mean BLL: 45.52 g/dl). Serum concentrations of the immunoglobulins IgG and IgA were greatly reduced among all of the lead-exposed workers compared with population standards but there were no changes in concentrations of IgM. In contrast to these findings, Borska et al. found that IgA is increased and IgM is decreased in welders (Refs. 17, 18) which supports the assumption that the reductions in IgG and IgM observed in welders by Ayatollahi were associated with lead and not with other components of welding fumes.

Dasdag et al. (Ref. 28) compared hematologic and immunologic parameters of 16 Turkish male welders with those of 14 healthy male non-welding controls who were from the same geographic area and had life styles similar to the welders. The following parameters were evaluated in blood samples from both groups: red blood cells, platelets, PMNs, lymphocytes, eosinophils, total white blood cells, and four subsets of T-lymphocytes were counted; hemoglobin concentrations and hematocrit were determined. Welders were found to have higher hematocrit levels than controls, and the number of helper T-cells and suppressor T-cells (as indicated by determination of the T lymphocyte surface antigens CD4 and CD8) were found to be significantly lower in the welders than in the controls. The observed differences were not biologically significant, however, as all values fell within normal clinical limits.

18. Effects on Reproduction

Sheiner et al. (Ref. 129) performed a case-control study that examined the influence of occupational exposures on male fertility. The cases included 106 male patients who had attended a fertility clinic in Israel during a 10-month period because of male fertility problems. The controls were the 66 male patients who had visited the clinic during that same time because of infertility problems associated with their wives. The participants were divided into eleven groups based on occupation.

Men with male fertility problems were significantly more likely to be working in industry and construction than were controls. No significant differences were found between cases and controls when exposures to welding, noise, and other physical and chemical agents were compared (see Table 13). The investigators concluded that male infertility was associated with working in industry and construction as compared with other occupations ($p = 0.044$). They noted that patients in this category tended to smoke more, and had more physically demanding work than the other occupations in the study group.

Kenkel et al. (Ref. 67) performed a retrospective study of occupations associated with male infertility using data archived at their fertility clinic in Münster, Germany. The analyses included 3313 men, mean age 32.8 years, who were patients at the clinic for at least one year during the period 1976 to 1996 and who lived in the district of Münster. These men were divided into 29 occupational groups and the relative sizes of the groups were compared with those of the entire male workforce of the district of Münster to examine whether any occupations were over- or under-represented among the patients. The percentage of men in the occupational group metal workers/welders was non-significantly lower among men who were being treated in the clinic than among men in the general population (Figure 3). Semen quality was examined in samples collected from 2054 of the patients in the study population. Farmers (n = 46) and painters/varnishers (n = 28) were the only occupational groups to show significant reductions in sperm count and concentration. Metal workers and welders (n = 20) comprised the only group to show a significant decrease in sperm motility. The authors suggested that the findings for metal workers/welders might be due to their exposure to radiant heat or to toxicants in the workplace.

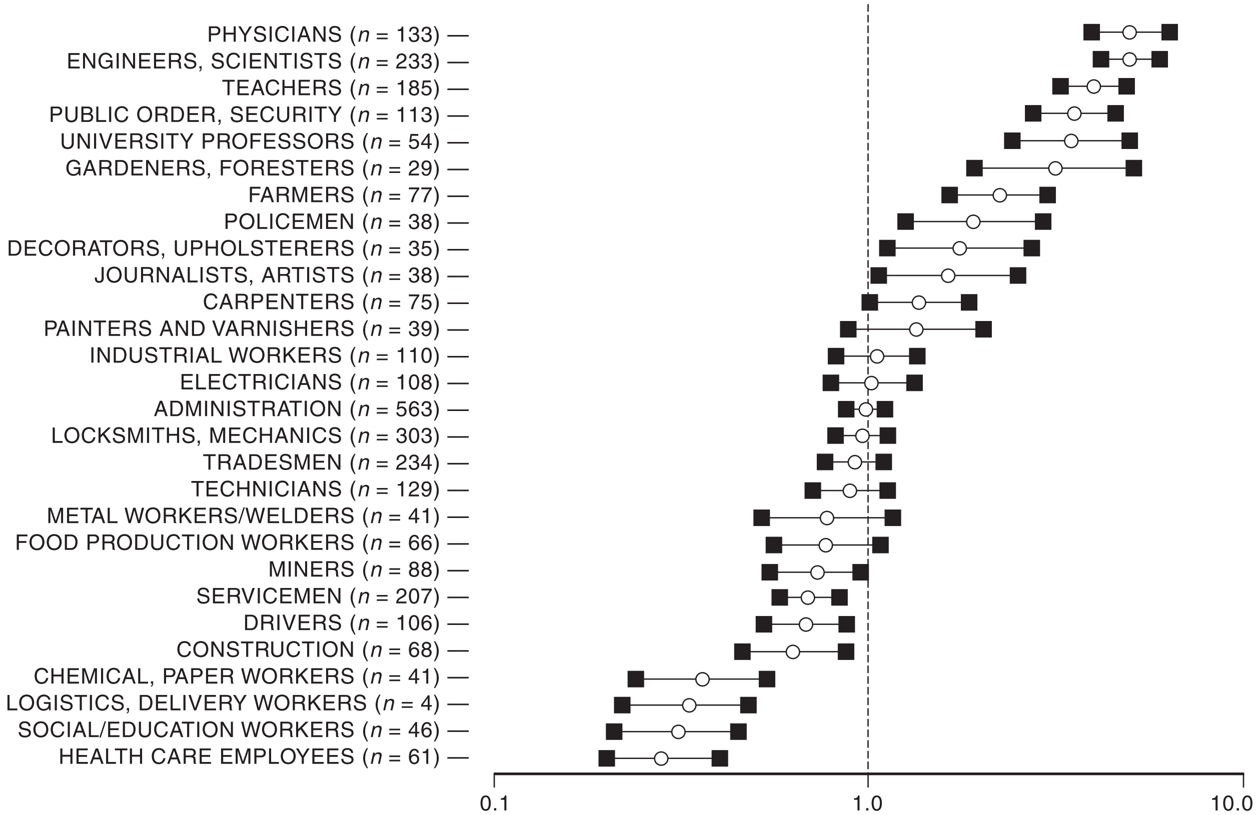
Auger et al. (Ref. 7) conducted a multicenter study to investigate the effects of environment, life style, and occupational factors on sperm morphology among 1001 men from four European cities: Turku, Copenhagen, Edinburgh, and Paris. Semen samples were collected from the male partners of pregnant women who were invited to participate in the study during their visits to prenatal care clinics. All of the pregnancies were

Table 13
Comparison of Occupational Exposures Reported by Patients with Male Infertility (Cases) versus Men whose Partners were Infertile (Controls)

Exposure	Cases (n = 106)	Controls (n = 66)	Probability[a] (p)
Chemical agents			
Metals	10 (9.7%)	5 (7.6%)	0.634
Pesticides	5 (4.9%)	6 (9.1%)	0.344
Solvents	9 (8.8%)	3 (4.5%)	0.369
Physical agents			
Noise	33 (32.4%)	16 (24.2%)	0.259
Radiation	5 (4.9%)	1 (1.5%)	0.406
Solar radiation	28 (272%)	20 (30.3%)	0.661
Heat	5 (4.9%)	3 (4.5%)	1.000
Vibrations	3 (2.9%)	2 (3.0%)	1.000
Welding	7 (6.8%)	3 (4.5%)	0.742

[a] None of the differences between cases and controls were statistically significant ($p < 0.05$).

Source: Data from Sheiner et al., Ref. 129.



Note: Age-adjusted odds ratios and 99% confidence intervals are shown by circles and squares, respectively. Occupations with odds ratios and confidence intervals greater than 1.0 (dotted line) are over-represented among patients of the fertility clinic compared with the normal population of the district of Münster.

Source: Kenkel et al., Ref. 67.

Figure 3—Frequency of Occupations Among Patients Attending the Fertility Clinic Compared with that of the same Occupation in the District of Münster

achieved by normal sexual intercourse. The participants were 20 to 45 years old and lived in the local area of the hospital where they were recruited. Semen samples from all cities were analyzed for number and types of abnormalities in sperm morphology in a single laboratory located in Paris.

The number of sperm defects and abnormalities varied significantly with the city in which the participants resided, and more abnormalities were found in the spring than in the winter. Several sperm defects were significantly associated with stress, the number of hours worked per week, and with occupation as a welder. Two specific types of sperm defects were found to be significantly more prevalent among the 15 subjects who had welded daily during the 3 months before the analysis compared with the 838 subjects who had never welded during this period. Since none of the participants in the study had experienced fertility problems, the biological significance of these observations is not known.

While it is well established that some paternal occupational exposures can affect fertilization, little is known about the potential effect of occupational exposures on early stages of embryogenesis. Tielemans et al. (Ref. 149) investigated whether male occupational exposures can influence the implantation of embryos in 726 couples undergoing *in vitro* fertilization at the University Hospital at Utrecht in the Netherlands. Implantation rates were measured by the number of gestational sacs divided by the number of transplanted embryos, observed by ultrasound at 6 to 7 weeks after embryo transplantation. Implantation rates were significantly reduced in couples in which the male partner was occupationally exposed to high levels of organic solvents and were significantly increased in couples where there had been paternal exposure to pesticides. The authors discussed a possible mechanism involving direct effects of defective sperm on the oocyte that could explain the latter finding. The probability of implantation was not affected by paternal exposure to metal dusts or welding fumes.

19. Health Surveys

In India, Prasad and Vyas (Ref. 112) compared general health and fertility rates of 100 welders and 41 controls (sewing machine operators and assembly workers). All participants had worked in their trade for at least 5 years and were of reproductive age (30 years or younger) at the start of their employment. Information about general health, employment history, accidental burns, fertility, and symptoms such as eye irritation, headache, and fatigue were collected by interview. Eye irritation was reported by 40% of the welders; 70% of the welders felt generally healthy compared with 80% of the controls. No differences in fertility rates were seen between the welders and controls.

Liubchenko and Vinnitskaia (Ref. 79) reported that surveys of 323 electric welders in a Moscow suburb showed that the occupational disease most frequently experienced by welders was pneumoconiosis. This was followed in decreasing frequency by neurosensory deafness, chronic bronchitis, and chronic manganese poisoning. The authors suggested that cancer of the larynx and lungs could also be considered to be occupational in origin.

20. Genotoxicity

Tests for DNA damage or chromosome aberrations are useful for predicting whether workers have been exposed to potentially carcinogenic chemicals. Using the comet assay, a technique that quantifies DNA strand breaks in single cells, Zhu et al. (Ref. 173) investigated whether occupational exposures in a Chinese bus manufacturing company are associated with DNA damage in lymphocytes isolated from blood obtained from 346 employees (106 women and 240 men). The subjects, chosen in part on the basis of their potential exposures to genotoxic agents, included 120 welders, 30 mechanics, 80 painters, 31 assemblers, 45 auxiliary workers, and 40 administrators. The mechanics were exposed to solvents, welders to welding fumes (neither the welding methods used nor the metal(s) welded were specified), painters and auxiliary workers, who occasionally assisted the painters, to benzene, toluene, and xylene. The administrators served as controls. Environmental measurements showed that painters were exposed to concentrations of benzene and toluene that were up to or greater than 2.5 times the Chinese MAC. Welding fume concentrations ranged from 1.1 mg/m^3 to 4.4 mg/m^3 and manganese dioxide in fumes ranged from 0.02 mg/m^3 to 0.11 mg/m^3 (MAC = 0.2 mg/m^3). DNA damage was greatest in lymphocytes from painters followed by auxiliary workers and mechanics. Each of these groups of workers had significantly more DNA damage than did administrators. There were no significant differences in DNA damage between administrators and welders or assemblers. The authors stated that significant differences may not have been seen between administrators and welders since the administrators may have had residual DNA damage remaining from the time they were production workers.

Borska and Tejral et al. (Refs. 16, 148) performed a study of blood chemistry and chromosome aberrations in eleven stainless steel welders and nine stainless steel grinders in the Czech Republic. Their average age was 31 years and they had worked at these jobs for an average of 8 years. The 20 healthy blood donors, average age 36 years, who served as controls had no known occupational exposures to toxic chemicals. All of the participants were male and 55% of the metal workers and 40% of the controls were smokers. Chromium concentrations in air samples collected during welding and grinding ranged from 0.56 mg/m^3 to 16.34 mg/m^3, and all exceeded the maximum permitted concentration of 0.1 mg/m^3. Nickel concentrations ranged from 0.34 mg/m^3–10.13 mg/m^3 and exceeded the permitted concentration of 1.0 mg/m^3 in some of the air samples. Manganese concentrations were within permitted values. Total concentrations of 12 polycyclic aromatic hydrocarbons (PAH) in air samples ranged from 300 ng/m^3 to 961 ng/m^3 which, the authors noted, was higher than PAH levels measured on busy city street intersections. No marked differences were found in the health status, in the complete blood count, or biochemical blood screening results between the metal workers and controls. More chromosomal aberrations were found in the exposed workers than in the controls which led the authors to conclude that a genotoxic risk is associated with the welding processes investigated.

Quievryn et al. (Ref. 114) measured DNA-protein cross links in peripheral blood lymphocytes obtained from 5 stainless steel welders and 22 controls. The welders performed oxyacetylene welding of chromium/nickel alloys without respiratory protection in an open environment. Welders had 4.1 times more DNA-protein cross links than did controls; this difference was statistically significant ($p = 0.01$). The investigators suggested that the genotoxic effects observed in the welders was caused by Cr(VI) exposure.

21. Effects of Chromium

Perforated nasal septa were detected in eleven welders during annual health examinations of 2869 welders conducted from 1997 to 2000 in a shipyard in Ulsan, South Korea. None of the eleven men had suffered from diseases or conditions that could have caused this condition. Six were symptom-free, five complained of nasal congestion, and one experienced anosmia (loss of the sense of smell). The eleven welders had worked at the shipyard for 12 to 22 years and only one of them had ever been exposed to chrome plating processes. Based on published reports that chrome platers are susceptible to nasal septum perforation resulting from exposure to Cr(VI), Lee et al. (Ref. 78) examined the chromium exposures of the welders at the shipyard where both stainless and mild steel welding were performed. Historical ambient air sampling data collected in the plant since 1991 did not reveal exposures to high levels of chromium. Environmental conditions at the shipyard had improved considerably since 1990 and exposures may have been higher before that time. In addition, breathing zone samples collected at the time of the study from 31 welders working in six areas where the eleven cases had been working showed mean Cr(VI) levels of 0.22 mg/m^3 with a maximum of 0.34 mg/m^3 in one of the areas (F Shop). The authors deemed this exposure to be sufficient to have caused perforation of the nasal septum. While the mean Cr(VI) levels in the other work areas were below 0.003 mg/m^3 and none of the eleven cases had elevated blood or urinary chromium levels, the authors argued that prolonged past exposures to the levels of Cr(IV) observed in F Shop could have been responsible for the nasal septum perforations observed in the welders.

Based on the premise that exposure to chromium increases free-radical species in the body, which in turn causes oxidation of plasma lipids with the potential for adverse biological effects, Ellis et al. (Ref. 35) compared plasma lipid oxidation and antioxidant levels in eleven welders who had a median duration of chromium exposure of 22 years with those in 15 age-matched controls who had no known chromium exposures. No significant differences in lipid peroxidation, plasma lipid susceptibility to oxidation, or total plasma antioxidant status were found between the welders and controls. However, only three of the welders were found to have elevated urinary chromium levels (>10.0 µg/g creatinine) suggesting that the mean chromium exposure among the group of welders may have been too low to have caused the anticipated effects. When the three welders with elevated urinary chromium were examined separately, they had higher plasma lipid peroxidation and greater lipid susceptibility to oxidation than did the rest of the study group. Recognizing that the small number of subjects with elevated urinary chromium severely limited the statistical power of this study, the investigators concluded that their results suggested that welders exposed to chromium may have increased plasma lipid oxidation which, they stated, requires further study.

22. Effects of Mercury

The case of a 40-year-old welder who suffered from acute mercury poisoning was described by Zlotkowska and Zajac-Nedza (Ref. 176). The exposure occurred when the welder used an oxyacetylene torch to cut mercury-covered tubes while working in the acetaldehyde production area of a large chemical plant in Poland. On the third day of this work, he experienced nausea, abdominal pain, headache, fever, and had symptoms of gingivitis. After being unsuccessfully treated for a week for gingivitis by a general physician, he consulted an occupational physician who suspected mercury poisoning. He was referred to a hospital where his urinary mercury levels were found to be very high (830 µg/l). He was treated with a chelator following which his symptoms subsided and the urinary mercury gradually declined towards normal. Measurements made in the plant at the time of his admission to the hospital indicated that the airborne mercury levels exceeded permissible occupational exposure limits (0.025 mg/m^3) whereas those taken some time before the incident were not elevated. The welder wore a face mask while cutting the contaminated tubes, but had not used respiratory protection appropriate for mercury exposure.

23. Effects of Lead

Hettmansberger and Mycyk (Ref. 54) described the case of a 57-year-old man who developed abdominal pain and lower back pain with no other symptoms over a period of several days. When he sought medical help, he appeared normal except for a depressed hemoglobin level and the appearance of blood in the urine. His symptoms still persisted after a 3-day hospitalization for a diagnostic work-up and treatment for suspected kidney stones. It was not until a follow-up visit after his discharge from the hospital that the physicians learned that he was a welder with exposure to lead fumes. At that time, he was placed on chelation therapy with dimercaprol for five days, and his symptoms resolved. The authors explained that symptoms of lead poisoning can be non-specific and may be mistaken for those of various illnesses including acute viral infection, gastroenteritis, acute appendicitis, kidney stones, and Guillain-Barré syndrome.

De Haro et al. (Ref. 29) noted that of the 45 adults reporting with lead poisoning to a poison control clinic in France between 1993 and 2000, 30 had been exposed to lead in the workplace. In a comment on the case report by Hettmansberger and Mycyk (Ref. 54), Suls (Ref. 144) stated that the most common exposure to lead among adults is occupational, and he stressed that, as illustrated by the case reported by Hettmansberger and Mycyk (Ref. 54), a thorough occupational history is essential in any patient who presents with a constellation of unexplained symptoms. Had the physicians been aware that the patient had been exposed to lead welding fumes, the lengthy diagnostic work-up and delay in treatment might have been avoided. He added that the finding of the lead poisoning case such as this one should be followed by a work-site evaluation performed in conjunction with a certified industrial hygienist or a health and safety officer to ensure that engineering and administrative controls and the patient's personal protective equipment are appropriate to the type of work being performed and are functioning properly.

24. Biological Monitoring

Kucera et al. (Ref. 72) measured levels of Cr, Mn, Mo, Ni, and V in samples of serum, blood, urine, hair and nails taken from 18 welders and two polishers of stainless steel vessels. Twenty agricultural workers served as controls. Biological samples were collected mid- week at the beginning of a work shift. Details concerning the plant, the aerosol monitoring results, and the metal welded are described in Section 5.0 of this volume (Ref. 73). Chromium levels were found to be significantly elevated in hair, nails, serum, and urine of the metal workers compared with controls. Molybdenum was significantly elevated in hair, and marginally significant elevations of manganese were found in whole blood samples.

The investigators considered the elevated concentrations of chromium in urine to be convincing evidence of occupational chromium exposure. They related these results to their findings that the chromium levels in the breathing zones of these subjects exceeded the MAL for chromium of 50 $\mu g/m^3$ during the time that they were engaged in welding or polishing, while none of the other elements tested were higher than their respective MALs (Ref. 73). Finally, the investigators related their findings of elevated chromium levels in biological fluids and tissues to their earlier observations of changes in the immune profile of welders from this plant (Ref. 17).

Luse et al. (Ref. 80) briefly described a study of the concentration of manganese in the hair and blood of 46 welders. The controls were randomly selected residents of Riga, Latvia, where the study was performed. Data concerning neuropsychiatric symptoms were obtained by questionnaire and each participant was subjected to a neurobehavioral examination. Manganese levels were 7.6 and 3.2 times higher in blood and hair, respectively, from welders than from controls. Impaired performance in motor function and attention tests was observed in some of the welders. The authors concluded that manganese levels in blood and hair could be used as an indicator for overexposure to manganese in workers.

Using the concentrations of 1-hydroxypyrene (OHP) in urine as a biomarker, Mukherjee et al. (Ref. 94) examined PAH exposure in two groups of boilermakers. Polycyclic aromatic hydrocarbons form during combustion of organic materials and some PAHs are known carcinogens. Pyrene, a major component of PAHs in industrial settings, is almost completely metabolized to OHP, which accounts for about 90% of the pyrene excreted in urine, making it a useful biomarker for exposure. 1-Hydroxypyrene was determined in multiple urine samples collected from two groups of boiler makers. The first group (n = 21) was recruited from a welding school. Their exposures were predominantly to fumes from welding mild steel. The second group (n = 20) worked at a power plant where they performed oxyacetylene cutting and arc welding to repair the interior wall of an oil-fired boiler which was coated with residual oil fly ash. About half the men in both groups were smokers. In non-smoking apprentice welders, there were no changes in OHP levels during the work shift and only small decreases over night. 1-Hydroxypyrene levels decreased during the work shift in urine from smokers. Among the power plant boiler makers, urinary OHP levels doubled during the 5-day workweek in non-smokers and increased less dramatically in smokers, reflecting their exposures to PAH in the fly ash. The investigators concluded that urinary excretion of OHP may be useful as a biomarker of PAH exposure in fly ash-exposed boilermakers, particularly in non-smokers.

Section Three
Investigations in Animals

25. Inhalation Studies

25.1 Respiration. Saito et al. (Ref. 123) measured the respiratory response of rats exposed to welding fumes and gases generated by a mild steel consumable electrode. The emissions generated by the electrode were analyzed in a separate study (Ref. 124) and described in Section 1.0 of this volume. For the inhalation study, fumes were generated by eight cycles of "bead-on-plate" welding for 6 minutes; successive cycles were separated by 9-minute pauses. Fume concentrations in the exposure chamber varied with the welding current and ranged from 34.2 mg/m^3 to 69.5 mg/m^3. Concentrations of ozone ranged from 0.14 ppm to 0.25 ppm and those of carbon monoxide ranged from 16 ppm to 21 ppm. Five rats were exposed to welding emissions for 2 hours and the effect on respiratory function was measured with a plethysmograph.

The rats exhibited rapid, shallow breathing immediately after the start of the first exposure cycle. The abnormal breathing continued for a few minutes and then returned to normal. The rapid, shallow breathing recurred, but was less severe, at the beginning of the second exposure cycle. The intensity of the respiratory response declined thereafter, until there was no change in breathing rates by the eighth and final exposure. The reason for this gradually decreasing respiratory response is not certain, but the investigators suggested that the reaction might be due to effects on olfactory function to which the animals gradually adapted.

25.2 Pulmonary Fibrosis. Yu et al. (Ref. 168) conducted a series of inhalation studies in rats which examined particle deposition and fibrogenic characteristics of fumes generated by SMAW of stainless steel. The diameters of the particles to which rats were exposed ranged from 0.023 µm to 0.81 µm with a geometric mean diameter of 0.1 µm. The concentrations of Fe, Cr, Mn, and Ni in the aerosol were constant over a 2-hour exposure period.

In the first study, rats were subjected to a single 4-hour exposure to a TWA fume particle concentration of 62 mg/m^3 and were sacrificed 0, 1, 3, 7, 10, and 14 days later. Histopathologic examination of the respiratory tract showed that welding fume particles were concentrated primarily in the small bronchioles and alveoli; there was no accumulation in the upper airways. Macrophages with ingested fume particles were seen in the areas where fume particles accumulated. The concentration of particles began to diminish at 7 days after exposure and, by 14 days, they were almost entirely cleared from the lungs.

The aim of the second study was to develop a pulmonary fibrosis model (Ref. 167). Groups of rats were exposed for 2 hours per day for 1, 15, 30, 60, or 90 days to TWA fume concentrations of 63.6 mg/m^3 ± 4.1 mg/m^3 (low dose) and 107.1 mg/m^3 ± 6.3 mg/m^3 (high dose). The animals in each group were sacrificed immediately after their final exposure.

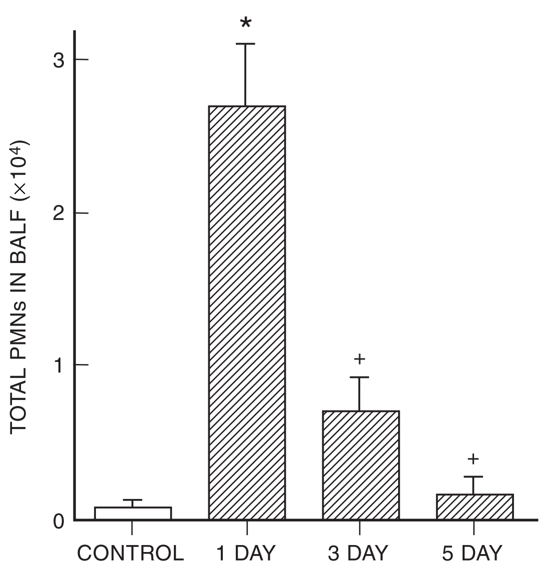
Histopathologic examination of respiratory tract tissues revealed little evidence of fibrosis in the low-dose rats, although particle-laden macrophages and lymphocytes were found in the alveolar region of the lungs after the second week of exposure. In the high-dose rats, there were particle-laden macrophages in alveolar spaces and signs of early fibrosis in the peribronchiolar and perivascular areas (i.e., areas around the perimeter of the bronchioles and blood vessels, respectively) after 15 days of exposure. By 60 days, granulomatous regions, distinct fibrosis in perivascular and peribronchiolar areas, and some interstitial fibrosis were evident. These findings became more intense after 90 days exposure. No significant histopathological changes were seen in the trachea or large bronchi.

Yu et al. (Ref. 166) later performed studies in which rats were exposed under the same conditions as in the previous work, but were allowed a 90-day recovery period following the last exposure before sacrifice. In the low-dose group, the particle-laden macrophages that had been observed in rats exposed for 15 to 30 days were no longer evident after the exposure-free recovery period. In both low- and high-dose rats exposed for 60 to 90 days, the particle-laden macrophages appeared as dense macules after the recovery period. In high-dose rats, the signs of fibrosis seen in the peribronchiolar and perivascular areas immediately following 15-day to 30-day exposures had completely resolved and were no longer evident after the recovery period. However, the fibrotic changes seen at 60 days and 90 days of exposure were not fully reversible after the 90-day recovery period. The investigators concluded that the damage from exposure to the low dose for up to 60 days was fully reversible but that fibrotic changes occurring by 60 days at the higher dose may not be. They calculated that the low and high doses used in the study would be equivalent to 20 mg/m^3 and 40 mg/m^3 when averaged over a 6-hour day which they equated to doses received by some workers in confined spaces.

25.3 Metal Fume Fever. The number of PMNs and macrophages is significantly elevated in BALF collected from human volunteers during the first 22 hours after 10-minute to 30-minute inhalation exposures to zinc oxide (ZnO) fumes. Cytokines released from these neutrophils are thought to be responsible for the symptoms of metal fume fever (Refs. 12, 13, 75). A short-term tolerance to metal oxide-induced metal fume fever can develop with repeated daily exposure to metal fumes. This tolerance is lost when exposure ceases and, hence, episodes of metal fume fever frequently occur on Mondays after a break from exposure over the weekend. Using the number of PMNs recoverable in BALF as an indicator of the development of metal fume fever, Wesselkamper et al. (Ref.

161) explored the mechanisms of pulmonary tolerance to inhaled ZnO in mice. Mice were exposed to by inhalation to 1.0 mg/m^3 ZnO for 1, 3, or 5 successive days. Acquisition of tolerance was assessed 24 hours after the exposures were completed by determining the numbers of PMNs in BALF.

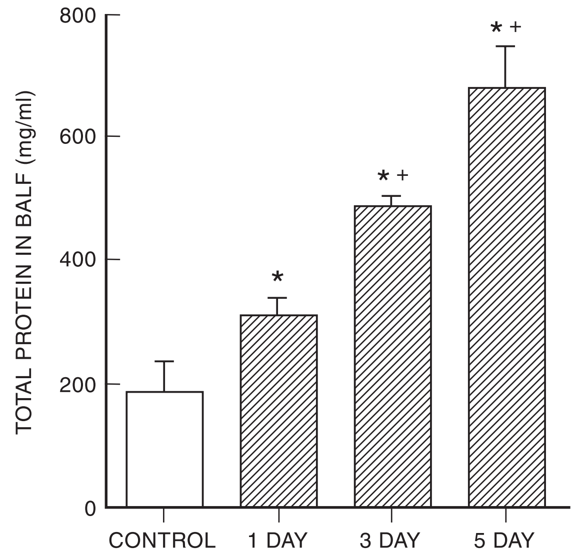
Concentrations of proteins in BALF and the histopathologic appearance of excised lung tissue were also examined at that time. The number of PMNs declined steadily with days of exposure; they were significantly elevated in mice after 1- and 3-day, but not 5-day exposures compared with unexposed controls (see Figure 4). The decline in the number of PMNs reflects the probable development of tolerance to ZnO in these mice. In contrast, protein concentrations in BALF increased with the duration of exposure and were significantly greater in mice exposed for 3 days and 5 days than in those exposed for 1 day (Figure 5). In addition, some histological changes were



Note: Values are means ± SE; * denotes significant difference from controls ($p < 0.05$); + denotes significant difference from the 1-day exposure group.

Source: Wesselkamper, Ref. 161.

Figure 4—Number of Polymorphonuclear Leukocytes (PMNs) in Bronchoalveolar Lavage Fluid (BALF) from Mice 24 hours after 3-hour Exposures to 1 mg/m^3 ZnO for 1, 3, or 5 Days



Note: Values are means ± SE; * denotes significant difference from controls ($p < 0.05$); + denotes significant difference from the one-day exposure group.

Source: Wesselkamper, Ref. 161

Figure 5—Total Protein in Bronchoalveolar Lavage Fluid (BALF) from Mice 24 hours after 3 hour Exposures to 1 mg/m^3 ZnO for 1, 3, or 5 Days

found in lungs tissue excised from animals exposed for 5 days, but not from those exposed for 1 day or 3 days.

To test whether tolerance was persistent, mice were exposed to ZnO for 3 hours per day for 5 consecutive days, allowed to rest for 5 days, and then subjected to a single 3 hour exposure to ZnO. The number of PMNs and protein levels in BALF did not differ significantly between these mice and those subjected to a single 3-hour exposure, suggesting that tolerance to ZnO is not persistent in mice. The loss of tolerance in mice parallels that seen in occupationally-exposed humans after a few days away from work. The investigators concluded that the decline of PMNs to near control levels after 5 days of exposure is a clear indication of the development of tolerance to metal fume fever in these mice. They noted, however, that even though the numbers of PMNs are at near normal levels after 5 days of exposure, the protein content of BALF is elevated, which indicates that the test animals did not become tolerant to ZnO-induced changes in lung permeability. In addition, examination of lung tissue removed from the test animals revealed an increase in lung changes with days of exposure. Thus, Wesselkamper et al. suggested that the development of tolerance to ZnO exposure may not necessarily be completely protective because injury to the lungs continued to progress throughout the 5-day exposure.

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Appendix A

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[a] and to a lesser extent in obstructive disease[b]
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. FEV_1 is reduced in restrictive lung disease and in obstructive lung disease.
FEV1 as a Fraction of FVC	FEV_1/FVC	Reduced in obstructive lung disease, normal or slightly increased in restrictive lung disease. FEV_1 is normally about 80% of FVC.
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. Positive responses at relatively low doses of methacholine are indicative of asthma.
Forced Expiratory Flow Mid range (25–75%) Terminal flow (75–85%)	FEF FEF_{25-75} FEF_{75-85}	Flow rate measured during forced exhalation. Reductions in mid range and terminal flow 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.

[a] Obstructive lung disease affects airflow through the airways and includes pathological conditions such as bronchial asthma, chronic bronchitis and emphysema.

[b] Restrictive lung disease affects diffusion of gases through the lung parenchymal tissue and includes conditions such as interstitial lung disease and diffuse pulmonary fibrosis.

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Appendix B
Occupational Epidemiology

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

Occupational epidemiology is the study of the occupational environment as a risk factor for disease in groups of workers. Compared with population studies, workplace studies have the **advantage** of the availability of 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. Thus, except for diseases that are rare in the general population, a large excess incidence of a disease must occur in the occupational group under study before causation can be established. This phenomenon is referred to as **the healthy worker effect. 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.

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 advantages 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 an excess incidence of a disease in the occupational group under study. This is particularly true for diseases such as lung cancer that 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 non-welders in the same factory). Dividing the number of cases in the study population by the expected number, based on incidence statistics for the general population, yields the **standardized incidence ratio (SIR)**. The **standardized mortality ratio (SMR)** is calculated from mortality data in the same manner. Both of these ratios are usually represented as percents [(number of cases observed/number of cases expected) × 100%].

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**). **Incident cases** refer to all new cases of the condition or disease under study that are identified within a specific population during a specified time period. The **odds ratio (OR)** for the disease in an occupational group (e.g., welders) is the fraction of cases who are members of the occupational group divided by the fraction of controls who are in the same occupational group. For example: OR for lung cancer in welders = (**percent** of cases who are welders)/(percent of controls who are welders). **Case-control studies** cannot provide an estimate of the true frequency of a disease in the population studied, because the control groups are small in size relative to the numbers in population studies and often are not chosen to represent the population at large. They have the advantages of small sample size, and relatively low expenditure of money and time. A major disadvantage is the difficulty of obtaining equally reliable information from cases and controls.

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 from lung cancer studies) 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**. Conversely, when the upper and lower boundaries of the **CI** are both less than one, the decreased incidence of the disease in the study group is also **statistically significant**.

From Shy (Ref. 131)