

Effects of Welding on Health, XIII



American Welding Society



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Effects of Welding on Health, XIII

Prepared for the
AWS Safety and Health Committee

Research performed by
Biomedical Toxicology Associates
6184 Viewsite Drive
Frederick, Maryland 21701

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

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



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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. CO₂-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 CO₂-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 $90^\circ \pm 15^\circ$ 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 chlorogenic 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.) Gustavsson 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 Hippel-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. Riihimäki 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 $\mu\text{mol/L}$ urine and 0.08, 0.14, and 0.46 $\mu\text{mol/L}$ serum for the no, low, and high exposure groups, respectively. Based on these data, the investigators estimated that aluminum concentrations of 4 $\mu\text{mol/L}$ –6 $\mu\text{mol/L}$ in urine and 0.25 $\mu\text{mol/L}$ –0.35 $\mu\text{mol/L}$ 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 $\mu\text{mol/L}$ for welders in this study was below the threshold for multiple adverse effects in aluminum welders estimated by Riihimäki 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 non-significantly 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 hyperuricemia 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 (CO₂) 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-CO₂ 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% CO₂ 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 photoreinitis 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 CO₂-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 $50 \mu\text{g}/\text{m}^3$. 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 $35 \mu\text{g}/\text{m}^3$. 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 dis-

trict 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 $0.2 \text{ mg}/\text{m}^3$, and 19% had exposures to iron greater than its TLV of $5.0 \text{ mg}/\text{m}^3$.

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/m³ and 5.0 mg/m³ 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/m³). 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 NO_x, CO, CO₂, and O₃. 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 austenitic stainless steel constructions in the Czech Republic. The median breathing zone concentration of chromium exceeded the maximum admissible limit (MAL) of 50 µg/m³ 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, Gustavsson 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 Hippel-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 protec-

tive 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 Sheno (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, hydro-