

Effects of Welding on Health, XII



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

Effects of Welding on Health, XII

Prepared for
AWS Safety and Health Committee

Research performed by
Biomedical Toxicology Associates
Frederick, Maryland

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Abstract

This literature review, with 216 citations, was prepared under contract to the American Welding Society for its Safety and Health Committee. The review deals with studies of the fumes, gases, radiation, and noise generated during various welding processes. Section 1 summarizes recent studies of occupational exposures, Section 2 contains information related to the human health effects, and Section 3 discusses the effects of welding on animals and cell cultures.



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Foreword

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

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

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Glossary*

ACGIH	American Conference of Governmental Industrial Hygienists
BALF	Bronchoalveolar lavage fluid
CI	Confidence Interval
Cr(III)	Trivalent chromium
Cr(VI)	Hexavalent chromium
ELF	Extremely low frequency
EMF	Electromagnetic field
FCAW	Flux cored arc welding
GMAW	Gas metal arc welding
GTAW	Gas tungsten arc welding
IgA	ImmunoglobulinA
IgM	ImmunoglobulinM
IL-1	Interleukin-1
IL-4	Interleukin-4
Leukocyte	White blood cell
MRI	Magnetic resonance imaging
n	number
nm	nanometer
NIOSH	National Institute for Occupational Safety and Health
OR	Odds ratio
OSHA	Occupational Safety and Health Administration
PAH	Polycyclic aromatic hydrocarbons
PEL	Permissible Exposure Limit
PET	Positron emission tomography
PMN	Polymorphonuclear leukocyte
PMR*	Proportional mortality ratio
RR*	Relative risk
SIR*	Standardized incidence ratio
SCE	Sister chromatid exchange
SMAW	Shielded metal arc welding
SMR*	Standardized mortality ratio
TLV	Threshold Limit Value
TNF	Tumor necrosis factor
TWA	Time-weighted average
µm	micrometer
µg	microgram
µmol	micromole per liter
µT	microTesla
UV	Ultraviolet
ZnO	Zinc oxide

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

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Supporting Organizations

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The Lincoln Electric Company

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

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Introduction

The health of workers in the welding environment is a major concern of the American Welding Society. To stay abreast of this subject, the health literature is periodically reviewed and published in the report *Effects of Welding on Health*. Eleven volumes have been published to date; the first covered data published before 1978, while the remainder covered 2- to 3-year periods between 1978 and December, 1996. The current report includes information published between January 1997 and December, 1999. 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 and cell cultures are discussed in Section 3.

Many of the studies on the effects of welding on health published during the current report period focused on matters that have been explored in the older literature. The question of whether or not welding causes a decrease in the function of the lungs or causes an increased incidence of pulmonary diseases such as bronchitis continues to be explored. Investigations of the association of asthma with welding increase in number as the prevalence of both occupational and non-occupational asthma increases in industrialized countries worldwide. As in the past, attention is focused on the incidence of lung cancer in welders and the contribution of the potential carcinogens nickel and chromium encountered in stainless steel welding to the incidence of the disease. Current studies do not indicate that stainless steel welders are at a greater risk for developing lung cancer than are mild steel welders, although they may be at a greater risk for experiencing changes in lung function than are mild steel welders. In addition, animal studies indicate that stainless steel welding fumes may elicit a stronger inflammatory response in the lungs than do mild steel fumes. The neurological effects of manganese received considerable attention during this report period and point to the strong need for the use of protective measures by workers exposed to this metal.

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Executive Summary

Workplace Exposures

Fume Sampling Procedures. In 1996, the European Committee for Standardization proposed a new European/International Standard for sampling airborne particles and gases generated during welding and allied processes. The requirements of this standard were evaluated by Chung et al. (Refs. 38, 39, 44) who conducted tests which showed that the choices of samplers and sampling procedures allowed by the standard could lead to an over- or underestimation of fume exposures. In these tests, samplers were placed on a life-size mannequin positioned over an automated welding test rig in a manner that represented a right-handed welder at work. No differences were seen in the exposures measured by five different sampling devices for inhalable dust. Placement of the sampler on the right or left side of the mannequin's face or under the chin yielded variable results leading the investigators to recommend that the sampler be placed on the side of the face where fume concentrations were visibly highest. Because the quantities of fumes collected when the sampler was placed on the lapel did not agree with those collected in the breathing zone, measurement of welding fume exposures by lapel sampling was not recommended. Finally, the draft standard allowed concentrations of fume constituents provided by the manufacturer's Material Safety Data Sheet to be used in lieu of analyzing individual components of collected fume samples. Chung et al. found that the fume composition determined by actual analyses of fumes generated in their laboratory did not agree completely with the analyses of fume components provided by the manufacturer. In particular, differences in the chromium content were observed among the fume compositions generated by FCAW and GMAW of stainless steel (Ref. 38) and reliance on the data sheets for fume composition would have led to underestimation of exposure to chromium.

Electromagnetic Radiation. Tenkate and Collins (Refs. 184, 186) used polysulfone film dosimeters to estimate the daily doses of ultraviolet (UV) radiation received by the eyes and skin of welders and nearby workers in a

metal fabrication workshop. All doses measured by body, ocular, and environmental badges were above the ACGIH maximum permissible exposure (MPE) limit. The ocular exposures measured for the welders and boilermakers were four and five times the MPE, respectively. Tenkate and Collins (Ref. 185) investigated the elements of helmet design and the angles of incident radiation that allow UV radiation to enter the helmet and reflect into the eyes. None of four helmet designs tested completely protected the eyes from exposure to UV radiation. When the UV beam was in a horizontal orientation, some UV radiation entered through the opening between the edge of the shield and the side of the face. UV radiation infiltrating through this area could be reflected off a corner section of the filter plate into the eye. When the UV beam was in a vertical position above the head, UV radiation could enter from behind the head through the gap between the back of the top edge of the shield and the top of the head. Because of its greater reflective surface area, a narrow helmet with a larger-than-standard filter plate permitted the greatest intensity of light to reach the eye.

Local Exhaust Ventilation. In their investigation of short-term effects of welding exposures on pulmonary function, Fishwick et al. (Refs. 69, 70) found that the use of local exhaust ventilation substantially reduced acute changes in lung function. They recommended that local exhaust ventilation, which they considered the most practical exposure reduction measure, be used wherever welding was done. In a survey of particulate exposures during welding and cutting of mild steel, aluminum, or stainless steel, Vernez et al. (Ref. 207) found that concentrations of particulate at work stations provided with local exhaust ventilation were about half those in stations without it.

The effectiveness of local exhaust ventilation may be influenced by workplace parameters and by working habits of the welders. Ludwig et al. (Ref. 125) measured breathing zone concentrations of radioactive thorium during GTAW with thoriated electrodes. They found that although the use of local exhaust ventilation reduced the total exposure received by individual welders, the position

of the welder's head in relation to the emission source was considered to be the main determinant of the welder's exposure. This finding is in agreement with earlier studies of the effects of the welder's position on exposure (Refs. 204, 20). Jankovic et al. (Ref. 94) measured breathing zone concentrations of thorium outside and within the welding helmet, with or without local exhaust ventilation, while welders were performing GTAW. When local exhaust ventilation was used, the concentration of radioactive aerosol outside the welding helmet was reduced forty-fold, but the concentration inside the helmet was reduced only twofold and was greater than the outside concentration. The authors observed that incoming air from local exhaust ventilation passed around the welder's body, creating eddy currents that could have caused portions of the fume to enter beneath the helmet.

Rappaport et al. (Ref. 155) found that local exhaust ventilation was much more effective during intermittent welding than during continuous welding. Local exhaust ventilation reduced exposure to total particulate by as much as 41% during intermittent welding but it only reduced exposure by about 6% during continuous welding. In accord with the findings of Rappaport et al., Bellido-Milla et al. (Ref. 21) observed that the use of local exhaust ventilation during continuous welding did not substantially reduce exposure to welding fumes. They noted that welders properly positioned the fume extractors when they began welding, but as they worked they moved without relocating them, which substantially reduced the benefits that may have been achieved by using local exhaust.

Effects on the Respiratory Tract

Pulmonary Function. Pulmonary function tests (spirometry) were used in several studies to measure changes in lung function that occurred during a welding shift or over years of exposure to welding fumes. Declines in pulmonary function tests or decrements relative to results in healthy individuals may be indicators of sensitivity to components of welding fumes or may be evidence of progress towards chronic lung disease. Two groups of investigators evaluated acute and chronic pulmonary responses to welding fumes. In a cross-shift study conducted in New Zealand, Fishwick et al. (Refs. 69, 70) found a small but statistically significant decline in lung function among welders compared with non-welders after completion of a work shift. Welders who did not use local exhaust ventilation were 22 times more likely to experience a measurable decline in lung function after 15 minutes of welding compared with those who did use ventilation. When the same population of

workers was examined two years later (Ref. 64), the welders and non-welders had similar annual declines in the pulmonary function variables measured. The annual decline in lung function over the two years was significantly associated with the acute change in lung function that had been observed in the cross-shift study. Decline in FEV₁ across a shift was a predictor of annual decline in FEV₁, which suggests the possibility that recurrent acute obstructive changes can lead to chronic airways obstruction.

The second set of studies, conducted in France by Sobaszek et al., was specifically designed to investigate the effects of fumes from stainless steel (SS) welding on lung function. The study of chronic effects compared pulmonary function measurements taken at the start of the workshift in stainless steel welders and in non-welders (Ref. 173). There were no significant differences in the results of lung function tests between the two groups; but, among the welders, increasing duration of the welding experience was significantly related to declining expiratory flow rates. In the cross-shift study, Sobaszek et al. (Ref. 172) found that significant declines in lung function at the end of a welding shift were associated with welding of stainless steel compared with mild steel, and with the use of SMAW compared with GMAW or GTAW.

Using magnetopneumography and spirometry, Nakadate et al. (Ref. 135) measured lung function and iron deposits in the lungs of welders before and after a 5-year period during which engineering changes in the plant where they worked reduced welding fume exposures. At the start of the study, decrements in lung function tests were significantly associated with the quantity of fume particles in the lungs. Five years later, improved air quality in the factory resulted in decreased quantities of welding particles in the lungs, but this did not result in improvements in pulmonary function.

Asthma and Chronic Bronchitis. In two large Swedish studies conducted by Toren et al. (Refs. 193, 194), a statistically significant increased risk for occupational asthma was associated with exposure to welding fumes. Exposure to welding fumes was also associated with an increased risk for occupational asthma in a hospital-based study in Italy (Ref. 126). Asthma-like symptoms seen in six Canadian welders examined by Contreras and Chan-Yeung (Ref. 48) were attributed to non-specific irritation rather than to sensitization to the components of welding fumes. In the group of New Zealand welders who were tested for pulmonary function before and after a work shift (Refs. 69, 70), the incidence of chronic bronchitis was significantly greater in welders with more than ten years experience than in those with less than four years experience (Refs. 32, 33).

Cancer

Lung Cancer. Nine studies found an excess risk for lung cancer among welders, but in only two of these studies was this risk statistically significant when the contributions of cigarette smoking and exposure to asbestos were factored into the risk calculation (Refs. 4, 99). In these two studies, a statistically significant elevated risks for newly-diagnosed lung cancer was found after the data were adjusted for smoking and asbestos exposure, among men who had ever had the job title of welder (Refs. 4, 99). An exposure-response relationship could not be established in either study.

In a study by Becker (Ref. 18) in which the risk for death from lung cancer was non-significantly greater in welders than in the general population, there were as many excess deaths from mesothelioma, a disease associated with asbestos exposure, as there were from lung cancer. Based on the assumption of a 1:1 ratio between asbestos-related pleural and lung cancers, Becker calculated that the excess lung cancer risk among welders was associated with asbestos exposure. Van Loon et al. (Ref. 201) found that an excess incidence of lung cancer cases among welders disappeared after the data were adjusted for exposure to asbestos, paint dust, and polycyclic aromatic hydrocarbons (PAH). In a study of lung cancer in Argentina, in which data were adjusted for smoking but not for asbestos exposure, Pezzotto and Poletto found that welders had a significantly elevated risk for squamous cell cancer of the lung. The relative risk for all lung cancers among welders was only slightly increased and was not statistically significant (Ref. 149). Another study of Argentinian men showed an elevated risk for lung cancer among welders, but it was based on five cases, and was non-significant (Ref. 128). Milatou-Smith (Ref. 132) compared lung cancer in stainless steel welders and railroad repair welders. There were non-significant increases in lung cancer in the combined group of welders compared with the general population and in the stainless steel welders compared with the railroad repair welders. Stern et al. (Ref. 176) found a non-significant excess risk for death from lung cancer among welders who worked in the construction industry compared with the rate in the general population. Danielsen et al. (Ref. 52) found steadily increasing rates of lung cancer with increasing years since first exposure as a welder, but, even after 40 years, the excess was not statistically significant. This study showed that siderosis is not a risk factor for lung cancer.

Cancer in Organs Other Than the Lung. In a multi-national cohort study that linked the incidence of cancer with occupation in three Scandinavian countries, Andersen et al. (Ref. 6) found a significant increase in cancers of the lung, pleura, kidney, and urinary bladder in weld-

ers. While the incidence of cancer of the gall bladder was significantly elevated, the investigators noted that the increased incidence of gall bladder cancer in welders was based on only twelve excess cases and may have been due to chance. In contrast to this study, Teschke et al. (Ref. 189) found no increased risk for urinary bladder cancer among welders in a case-control study conducted in British Columbia.

Gustavsson et al. (Ref. 76) conducted a community-based case-control study of the incidence of cancer of the upper digestive and respiratory tract in two densely populated regions of southern Sweden. Statistically significant risks of cancers of the throat and larynx were associated with more than 8 years of exposure to welding fumes. Laryngeal cancer was also associated with exposure to asbestos. Exposure to welding fumes was not significantly associated with a risk for cancer of the oral cavity in this study or in a case-control study in northern Sweden conducted by Schildt et al. (Ref. 162). In an ongoing study of cancer mortality among welders in Germany, Becker (Ref. 18) found that welders who used SMAW but not other processes had a significantly higher mortality from brain cancer, compared with the general population. A significant excess risk for pancreatic cancer was found in the occupational group of plumbers and welders in a study by Ji et al. (Ref. 97).

Four studies examined the risk of welders for non-Hodgkin's lymphoma (NHL) (Refs. 6, 49, 50, 65, 66, 87). A positive association was found only in a case-control study conducted by Fabbro-Peray and colleagues in a region of France with a high incidence of NHL (Refs. 65, 66). Welders were found to have an increased risk for multiple myeloma in a large case-control study conducted by Costantini et al. (Refs. 49, 50) but not in the multi-national cohort study conducted by Andersen et al. (Ref. 6). Neither of the latter two studies found an association between welding and leukemia.

Metal Fume Fever/Pulmonary Inflammation

Past work by Blanc et al. (Ref. 25) has suggested that metal fume fever is mediated by cytokines released from macrophages and other leukocytes during phagocytosis (engulfment of foreign particles) of metal oxide particles. Tumor necrosis factor (TNF), interleukin-1 (IL-1), and IL-8 become elevated in the lungs following inhalation of zinc oxide (ZnO). These cytokines may be involved in recruitment of other inflammatory cells (e.g., neutrophils, lymphocytes, and macrophages) after exposure to some dusts, which would account for the elevation of neutrophils in the lungs that occurs during

metal fume fever. In addition, the synthesis of IL-8 is stimulated by IL-1 and TNF, which is in accord with findings that IL-8 appears later in bronchoalveolar lavage fluid (BALF) than TNF following exposure to ZnO (Ref. 25). Finally, some cytokines (e.g., TNF, IL-1) are pyrogens and can cause an elevation in body temperature.

Kuschner et al. (Ref. 115) found that the concentrations of the cytokines IL-1, IL-6, IL-8, and TNF were significantly elevated in bronchoalveolar lavage fluid (BALF) collected from healthy volunteers 3 hours after inhalation exposure to ZnO fumes. The numbers of white blood cells (macrophages, neutrophils, lymphocytes) were not elevated at this time. An earlier study by these investigators had shown that TNF, but not the other cytokines, had declined significantly by 20 hours, and neutrophils were significantly higher at 20 hours than at 3 hours after exposure (Ref. 114).

In a parallel study, Kuschner et al. (Ref. 116) exposed human volunteers to magnesium oxide instead of ZnO. None of the subjects experienced any of the symptoms of metal fume fever and there were no significant changes in the concentrations of any of the four cytokines studied or in the numbers of white blood cells in BALF. Thus, the metal fume fever response to inhaled particles may be specific to certain metals.

In vitro studies by these investigators (Ref. 113) demonstrated that cultured monocytes (immature macrophages) released dose-dependent concentrations of TNF into the culture medium 3, 8, and 24 hours and IL-8 at 8 and 24 hours after treatment with ZnO. The sequential appearance of TNF and IL-8 mimicked that seen in BALF from ZnO-exposed human volunteers (Ref. 25). The investigators concluded that mononuclear inflammatory cells (macrophages) are probably the primary source of IL-8 and TNF in the lungs of humans exposed to ZnO fumes.

Lindahl et al. (Ref. 120) examined the possible role of another aspect of leukocyte activity, the respiratory burst, in the mediation of metal fume fever. When macrophages engulf foreign bodies such as bacteria or welding fume particles, they produce a variety of highly reactive oxygen species (ROS), including superoxide, hydroxyl radicals, and hydrogen peroxide. The ROS are important for bactericidal activity. They can act by altering the permeability of cell membranes and by reacting with the pathogen's macromolecules. Reactive oxygen species can also react with the host's macromolecules, causing deleterious effects such as strand breaks in DNA. Lindahl et al. demonstrated that exposure to ZnO and ZnCl₂ stimulates the release of ROS from cultured human neutrophils. The concentration of ROS increased to a maximum about 35 minutes following exposure to ZnO and at about 80 minutes following exposure to ZnCl₂. Corresponding concentrations of other metals (Cd²⁺, Cr²⁺, Cr³⁺, Fe²⁺,

Fe³⁺, Ni²⁺, Co²⁺) did not have this effect. The authors concluded that ROS might play a role in the pathogenesis of metal fume fever.

Pulmonary Inflammation. The inflammatory process, now believed to be involved in the progression of metal fume fever, is also responsible for the development of more serious chronic conditions such as pulmonary fibrosis and interstitial lung disease. Studies by Antonini et al. (Refs. 10, 11) showed that fumes generated by SMAW of stainless steel (SMAW-SS) produce a greater inflammatory response, as measured by concentrations of neutrophils, TNF, and IL-1 in BALF, than do fumes from GMAW of mild steel (GMAW-MS). In vitro studies conducted with macrophages isolated from untreated rat lungs by bronchoalveolar lavage showed that SMAW-SS fumes were more toxic and produced greater quantities of ROS than did GMAW-SS fumes. GMAW-MS fumes were the least toxic to isolated macrophages. A third study by these investigators showed that intratracheal instillation of freshly formed GMAW-SS fumes caused a greater inflammatory response in rat lungs than did fumes aged for 1 to 35 days before administration (Ref. 9), apparently due to the presence of ROS on the surfaces of newly formed fume particles. These results would suggest that studies of the health effects of welding fumes, whether conducted in animals or in vitro with cultured cells, would yield the most meaningful results if freshly-generated fumes are used.

Effects of Manganese

Excessive exposure to manganese can result in neurological damage, causing an array of symptoms, referred to as manganism, that resembles those of idiopathic Parkinson's disease.

Manganism and Parkinson's disease are both caused by degeneration of cells in the area of the brain called the basal ganglia which is responsible for producing smooth, coordinated movements. Characteristic high intensity signals confined to parts of the basal ganglia can be observed by magnetic resonance imaging (MRI) of persons with excessive manganese exposure. These manganese-related changes in MRI scans disappear within months after exposure to manganese has ceased, regardless of whether or not permanent neurological damage has occurred (Refs. 3, 13). A study conducted by Kim et al. of 34 asymptomatic manganese-exposed welders showed that the increased signal intensities in MRI scans reflects recent exposure to manganese, but does not necessarily indicate the presence of disease processes (Ref. 107).

In Parkinson's disease, there is a deficiency in the production of dopamine, a neurotransmitter vital to normal

nerve function. Treatment of Parkinson's disease patients with L-dopa, a metabolic precursor of dopamine, provides limited symptomatic relief. Wolters et al. (Refs. 163, 210) found a reduced uptake of 6-[^{18}F]fluorodopa (^{18}F -dopa) by the striatum of the basal ganglia in positron emission tomography (PET) scans of patients with Parkinson's disease but not in those with manganism. This phenomenon has been used to differentiate between the two syndromes. In a case described by Kim et al. (Ref. 105), a cranial MRI of a 48-year-old welder with signs of parkinsonism showed the high signal intensities that are characteristic of manganese poisoning. Concentrations of manganese in his blood were elevated, a shirt that he had worn for 2 days at work was found to be contaminated with manganese, and air sampling in the factory where he had last been employed indicated that he had probably been exposed to excessive levels of manganese. Despite the strong evidence that the welder had experienced excessive manganese exposures, based on PET scans which showed a reduced uptake of ^{18}F -dopa, it was concluded that he had idiopathic Parkinson's disease rather than manganism.

Ahn and Lee (Ref. 3) evaluated cognitive function in five welders who had histories of chronic manganese exposure and had MRI patterns indicative of manganese exposure. All five welders were experiencing fatigue, forgetfulness, and irritability but had none of the cardinal signs of parkinsonism. Neuropsychological tests indicated impairments of working memory, executive function, and attention span. Four of the welders also exhibited personality changes. Lucchini et al. (Ref. 124) also showed that early signs of manganese-related neurotoxicity can be detected in manganese-exposed workers in the absence of clinical signs of manganism. Neurobehavioral tests administered to 61 ferroalloy workers who had had long-term exposures to low levels of manganese showed impairments in short-term memory, in some basic tremor parameters, and in motor functions requiring alternating and rapid movements. No signs of neuropsychological disorders were detected.

Racette et al. (Ref. 152) compared the symptoms and disease course in fifteen welders with parkinsonism with that of two sets of controls with idiopathic Parkinson's disease. The severity of the disorder was similar in welders and controls. They exhibited no significant differences in the frequency of the cardinal signs of Parkinson's disease or in the frequency of clinical depression, dementia, and psychosis. In addition, the family history of Parkinson's disease and the response to treatment with L-dopa were similar in welders and controls. Cranial MRI scans performed on eight of the welders showed no signs of the high intensity signals typical of manganese-exposed workers. ^{18}F -dopa PET scans of two welders and thirteen controls were typical of

idiopathic Parkinson's disease. The age of onset of parkinsonism was the only clinical difference observed between the welders and controls. The investigators speculated that an agent in welding exposures may accelerate the development of Parkinson's disease in persons who might otherwise have developed it later in life or who are genetically predisposed to early onset Parkinson's disease. They concluded that parkinsonism in welders differs from idiopathic Parkinson's disease only in age of onset and that "welding may be a risk factor for" Parkinson's disease.

A potential weakness in this conclusion is that the PET scans provide the strongest evidence for excluding manganese as the basis for parkinsonism in the welders studied, yet they were performed on only two of the fifteen welders. A stronger conclusion might have been reached had PET scans been performed on a larger number of the welders in the study. In addition, occupational histories were not provided for the welders so it is not known whether they had been exposed to excess levels of manganese earlier in their careers. It is essential that manganese exposure, a known cause of parkinsonism that is faced by welders using some processes, be ruled out before the postulate can be accepted that welding is a risk factor for Parkinson's disease.

In their letter to the editor, Sadek and Schulz (Ref. 160) suggested that differences in MRI and PET scans were not seen by Racette et al. because, by chance, welders with manganism were not included in the study. They presented the alternative argument that, at an early stage, manganism may differ from idiopathic Parkinson's disease in several ways, including cognitive disturbances, emotional lability, and some physical signs that may not appear until later in the course of idiopathic Parkinson's disease. At a later stage, manganism "may be very indistinguishable from" and can easily be classified as early-onset idiopathic Parkinson's disease. Because the MRI scans will appear normal within months after exposure to manganese has ceased in persons who had been previously exposed to manganese, and because the effects of manganese may be cumulative (Ref. 124), MRI scans cannot be used to rule out past manganese exposures. Sadak and Schulz further pointed out that manganism is a progressive disease, and symptoms may continue to worsen long after exposure to manganese has ceased, which would increase the difficulties of distinguishing between manganism and Parkinson's disease. Thus, they concluded that some or all of the cases that Racette et al. classified as idiopathic Parkinson's disease in the welders may have actually been manganism.

Genetics and Manganism. In a case-control study of welders and ferromanganese workers who had been occupationally exposed to manganese, Zheng et al. (Refs. 212, 213) found that a variant of a gene that

reduces susceptibility to Parkinson's disease also reduces susceptibility to manganism. Individuals who had only the variant form of this gene had a 90% decreased risk of developing chronic manganism compared with persons in whom both copies of the gene were the wild-type (the form of a gene that occurs most frequently within a population). In addition, they found that persons who carry this genetic variant tend to develop manganism 10 years later than other persons with similar exposures to manganese. Thus, it may not be possible to distinguish between manganism and Parkinson's disease on the basis of a familial history of the disorder.

Effects on Reproduction

Three studies were conducted which used the time-to-pregnancy approach (TTP, the time from which the use of contraception is stopped until the time conception occurs) as a measure of fertility in welders and other workers (Refs. 85, 175, 191). None of these studies found statistically significant differences in the pregnancy rates among welders and controls. Hjollund et al. conducted a comprehensive fertility study of welders in Denmark that examined semen quality, rates of fertility, and rates of spontaneous abortion in a cohort of 406 couples in which 130 of the male partners were welders (Refs. 83–85). The effects of extremely low frequency (ELF) magnetic fields on fertility were also examined in a subgroup of the study population (Ref. 86).

Paternal stainless steel welding, but not mild steel welding, was associated with a significantly increased risk for spontaneous abortion, but this was the only positive effect observed in this study. Differences in pregnancy rates between welders and non-welders were not statistically significant, and neither the welding method used nor the metal welded affected rates of conception. In addition, no significant differences between welders and controls were observed in any of the measures of semen quality studied or in levels of sex hormones, and exposure to ELF magnetic fields did not affect fertility. The investigators noted that welders had relatively low exposures to welding fumes and cautioned that the negative findings obtained in their study may not apply to populations with high-level exposure to welding fume or to welders exposed to other putative hazards to fertility such as heat.

Spinelli et al. examined the effects of occupation on the fertility of 662 couples selected from the general population in Italy (Ref. 175). A non-significant difference was observed in the TTP between fathers who were exposed to welding fumes and those who were not. This difference was not statistically significant. Thonneau

et al. (Ref. 191) examined the relationship between fertility and male occupational heat exposure. Pregnancy was achieved within 3 to 6 months by a smaller percentage of the welders' partners than by the controls, but this difference was not statistically significant.

Two studies of semen quality found a greater incidence of abnormalities in welders than in controls. Both studies were conducted with men who had provided semen samples to fertility clinics. In the first study, the incidence of defects in any of the measured semen parameters was 25% among patients who were white collar workers, 47.7% among fitter-welders, 68.8% among machinery operators, and 85.7% among workers in the chemical and petroleum industries (Ref. 78). The second study used two different statistical approaches to examine the relationship between occupational exposures and semen quality (Ref. 23). Significant changes in 2 of 13 parameters of semen quality were observed by the analysis of continuous variables, while none were observed by the more traditional case-control approach in the semen from the 14 men in the study group who were currently or recently employed as welders or flame cutters.

Effects on the Immune System

Three studies examined the effects of welding on the immune system using assays including the concentrations of immunoglobulins in serum, number and function of lymphocytes (B and T cells) in blood, and activity of leukocytes isolated from blood. Results from two of these studies (Refs. 77, 195) suggest that the effects of welding on the immune system are minimal when fume exposures are lower than permissible values. The first study was conducted by Tuschl et al. with welders who used primarily GTAW and GMAW to weld stainless or mild steel (Ref. 195). Personal air monitoring indicated that the welders were exposed to average fume concentrations of 5.3 mg/m³. The only significant effect seen was a reduction of the function of natural killer (NK) cells, a form of lymphocyte that destroys a variety of foreign cells and tumor cells. In the second study, the immune status of welders who conducted SMAW of stainless steel was evaluated by Hanovcova et al. before and after ventilation was improved in the plant (Ref. 77). Air sampling conducted early in the study showed concentrations of chromium, nickel and manganese that were well in excess of maximum allowable concentrations. At this time, the number of T lymphocytes and the concentrations of lysozyme were elevated, and the activity of phagocytic cells was depressed in the welders. After improvements were made in the workplace, only one welding station had levels of chromium in excess of

the allowable standard and the immune system parameters approached control values for all the welders. In the third study, Borska et al. examined parameters of the immune system of welders who performed SMAW of stainless steel (Refs. 29, 30). Levels of chromium, nickel, manganese, and PAH measured in workplace area sam-

ples were below maximum allowable concentrations. Concentrations of IL1, lysozyme (a bactericidal enzyme released from activated macrophages), and the immunoglobulin IgA were elevated, and concentrations of IgM and the number of cells capable of phagocytosis were decreased in the blood from welders.

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Technical Summary

The Exposure

Analytical Methods

Inductively-Coupled Plasma Mass Spectroscopy. Because it can detect very low concentrations of metals and can measure a number of metals simultaneously with high precision, Apostoli et al. (Ref. 12) used inductively-coupled plasma mass spectroscopy (ICP-MS) to measure the concentrations of metals in fumes produced by eight welding procedures. The number of metals detected ranged from five in fumes from GMAW of aluminum, to sixteen in fumes from SMAW of stainless steel, and 23 in fumes from SMAW of mild steel. Guidotti (Ref. 75) described the use of ICP-MS for obtaining trace element profiles in blood, serum, and urine of workers from different occupational settings. He pointed out that ICP-MS is especially useful for measurement of metals that are present in very low quantities in biological fluids.

Aluminum. Valkonen and Aitio (Ref. 197) described a method for determination of aluminum in urine and serum using platform atomization in pyrolytically coated graphite tubes after fourfold dilution with nitric acid. Using this method, the mean concentration of aluminum in a healthy, non-exposed population was found to be 0.06 $\mu\text{mol/L}$ in serum, and 0.33 $\mu\text{mol/L}$ in urine. The average concentration of aluminum in urine samples collected from 3312 Finnish workers, who were occupationally exposed to aluminum and were primarily aluminum welders, was 1.4 $\mu\text{mol/L}$.

Chromium. The Standards, Measurements and Testing Programme of the European Commission conducted an interlaboratory study to develop reference materials for the purpose of providing laboratories with a means to check and improve analytical procedures for measuring chromium species in welding fumes (Refs. 43, 151). Ten European laboratories participated in the certification of the reference materials using various spectrophotometric methods, including electrothermal atomic absorption spectrometry, flame atomic absorption spectrometry, in-

ductively coupled plasma atomic emission spectrometry, and isotope dilution mass spectrometry (IDMS). The results obtained by the different laboratories were in good agreement.

Fume Composition

Using IDMS, Nusko and Heumann (Ref. 143) measured the concentrations of trivalent [Cr(III)], hexavalent [Cr(VI)] and elemental chromium in samples of fumes generated by SMAW, GMAW, and GTAW of stainless steel. The highest concentrations of Cr(VI) were generated by SMAW and GTAW of stainless steel (29.1 $\mu\text{g/mg}$ and 9.3 $\mu\text{g/mg}$, respectively). Dennis et al. (Ref. 57) described the effects of flow rate and welding voltage on the relationship between Cr(VI), ozone, and ultraviolet (UV) radiation during GMAW.

Workplace Exposures

Particle Size. Sioutas (Ref. 166) compared the atmospheric concentrations of fine particles in the areas of four different processes (heat-treating and brazing, welding, machining, and grinding) in an automotive plant. The concentration of fine particles was highest in the aluminum machining area followed by that in the welding area. Okamoto et al. (Ref. 145) examined the ratio of the quantity of respirable to inhalable particulate in workplaces where grinding, powder handling, metal casting, welding, and miscellaneous activities such as wood or metal cutting and production of metal leaf were performed. The ratio was highest in shops where welding took place and lowest in foundries.

Sampling Procedures. Chung et al. (Refs. 44, 38, 39) evaluated the new European/International Standard for sampling of airborne particles and gases generated during welding and allied processes proposed by the European Committee for Standardization and found that the allowable choices of samplers and sampling procedures could lead to an over- or underestimation of fume

exposures. Their findings indicated that lapel samplers were unreliable for measuring exposures to welding fumes and that reliance on data sheets for fume composition could lead to underestimation of exposure to fumes from some welding processes.

Iron Oxide. Using data obtained from records of OSHA inspections (IMIS) conducted from 1979 to 1989, Gomez et al. (Ref. 74) examined the effects of plant size, passage of time, and other variables on levels of personal exposures of welders working in metal fabrication to iron oxide. The mean exposures to iron oxide were below the OSHA Permissible Exposure Limit (PEL) and were found to be unchanged during the 10 year period examined and to be unaffected by the presence or absence of union representation or the size of the companies in which the welders worked.

Lead. In a survey of lead levels in personal air sampling data entered by OSHA compliance officers into the IMIS database for workers in the construction industry during the years 1984 through 1988, Jacobs (Ref. 93) found that lead levels in over 60% of the samples collected from workers in bridge, tunnel, and elevated highway construction and from workers in wrecking and demolition were greater than the OSHA PEL. In 1995, Nelson and Kaufman (Ref. 138) surveyed selected non-construction businesses in Washington State to determine the number of workers with potential lead exposure. Awareness of and compliance with the standard increased with the size of the plant and with the presence of labor unions representing the workforce.

Dioxins. Menzel et al. (Ref. 131) showed that dioxins can be generated during thermal oxygen cutting of contaminated materials. They found that dioxin exposures are not associated with welding of clean steel and are probably not associated with thermal oxygen cutting of virgin steel.

Ventilation. Rappaport et al. (Ref. 155) assessed personal exposures to total fume, manganese, nickel, and chromium among boilermakers, ironworkers, pipefitters, and welder-fitters at nine construction sites in the USA. They found that use of local exhaust reduced exposure, and exposure was increased when welding was continuous rather than intermittent. Using the statistical method of analysis of variance, Bellido-Milla et al. (Ref. 21) demonstrated that welding in an enclosed space, welding in a sitting position, and using automatic welding machines increased fume concentrations in the breathing zone. In accord with the findings of Rappaport et al. (Ref. 155), the use of local exhaust ventilation during continuous welding did not substantially reduce exposure to welding fumes or their constituent metals. Vernez et al. (Ref. 207) surveyed particulate exposures among a

population of 142 metal workers. They found that the concentrations of particulate measured at the stations provided with local exhaust were about half those in stations without it.

Thorium

The radioactive metallic element thorium is incorporated into tungsten electrodes to improve their arcing properties and their durability. Larocche et al. (Ref. 117) examined the potential for thoriated electrodes to introduce radiation hazards into the workplace when they are originally ground to produce a sharp tip, when they are re-ground, and when they are used during gas tungsten arc welding. In addition, they measured the amount of radioactive material that may be removed during handling of these electrodes. The sum of all of these exposures for welders using thoriated electrodes was estimated to be below the annual limit of 5 rem, set by the U.S. Nuclear Regulatory Commission. Ludwig et al. (Ref. 125) measured radioactivity in the breathing zones of 26 welders during welding and grinding operations with thoriated tungsten electrodes. Based on these measurements, the estimated annual inhaled dose for five of the welders exceeded the annual limit of 0.1 rem that is recommended for exposure of the general population by the International Commission on Radiological Protection, but none of the welders was found to be in danger of exceeding the occupational standard of 5 rem. Jankovic et al. (Ref. 94) also measured breathing zone concentrations of thorium during welding and grinding. Local exhaust ventilation provided the greatest reduction in breathing zone concentrations of thorium during welding, but when exhaust ventilation was not used, the welding helmet provided a substantial amount of protection. Concentrations of radioactive thorium measured during welding were well below a limit derived from the permissible annual dose of radiation. Higher concentrations of radioactivity were measured during grinding. Because these exposures were brief and infrequent, accumulated doses would not approach permissible annual limits.

Electromagnetic Radiation

Tenkate and Collins (Refs. 184, 186) used polysulfone film dosimeters to estimate the daily doses of UV radiation received by the eyes and skin of welders and nearby workers in a metal fabrication workshop. All doses measured by body, ocular, and environmental badges were above the ACGIH maximum permissible exposure (MPE) limit of 3 mJ/cm² for UV radiation. The ocular exposures measured for the welders and boilermakers were four and five times the MPE, respectively,

indicating that UV radiation can infiltrate the welding helmet. Tenkate and Collins (Ref. 185) investigated the elements of helmet design and the angles of incident radiation that allow UV radiation to enter the helmet and reflect into the eyes. None of the four helmet designs tested completely protected the eyes from exposure to UV radiation. The primary routes of UV infiltration were from the top and the back of the helmet. When the UV beam was in a horizontal orientation, some UV radiation entered through the opening between the edge of the shield and the side of the face.

Electromagnetic Fields

Skotte and Hjollund (Ref. 170) fitted welders and metal workers with exposure meters over periods of one to three days. The highest average workday exposure to electromagnetic fields (EMFs) (21.2 μ T) was recorded among welders engaged in SMAW using alternating current. Welders using GMAW (DC) had an average daily exposure of 2.3 μ T. Karlsen et al. (Ref. 100) used personal exposure meters to measure welders' exposures to EMFs during seven different welding processes. The highest maximum average exposures were found during SMAW (AC), followed in descending order by GTAW (AC or DC), SMAW (DC), GMAW (DC), FCAW (DC), and spot welding.

Hygiene and Work Practices

Accident and Sick Leave Rates. Using workers' compensation claims rates, Dement and Liscomb (Ref. 55) analyzed accident rates among workers in the residential construction industry in North Carolina. Welders and cutters had the highest number of injuries followed in descending order by insulators, roofers, mechanics and repairers, carpenters, and plumbers. Bylund and Bjornstig (Ref. 37) analyzed the incidence of non-fatal occupational injuries among the 2156 mechanics and construction metal workers who worked in Umea, Sweden, during the year 1985. Of the 470 welders in the cohort, 94 had suffered injuries on the job. The incidence of injury was highest among shop mechanics, followed by plumbers, and welders. Kosmider et al. (Ref. 110) found that welders, fitters, electrical mechanics, and platers had the largest number of work-related accidents at the Szczecin Shipyard in Poland.

Szubert and Sobala (Ref. 181) analyzed the relationship between absenteeism rates and duration of employment among workers in a Polish automobile plant. For most workers, the rate of absenteeism decreased with the duration of employment. This negative relationship was not true, however, for welders and drivers, which may be

a reflection of the development of work-related disease. In a study of sick leave rates resulting from temporary disability due to musculoskeletal disorders, Burdorf et al. (Ref. 35) found that back, knee, and shoulder pain were the most frequently reported disorders by welders. There was no association between absences resulting from musculoskeletal disorders and duration of employment, but workers who took sick leave due to pain in the back, neck, shoulder, or upper or lower extremities were at higher risk of incurring sick leave from the same cause in the following year.

Electrocutions. The National Institute for Occupational Safety and Health (NIOSH) (Ref. 140) reported that electrocutions were the fifth leading cause of death in the workplace and accounted for 7% of all workplace fatalities between 1980 and 1992. Of the 244 electrocutions that occurred from 1982 through 1994, six occurred among welders.

Forensic Diagnosis of Electrocution. Using a new application of a histological stain, Imamura et al. (Ref. 92) demonstrated that electrocution was the cause of death of a 30-year-old welder who died while using an arc welder to mend drainpipes.

Explosions. The death of a welder caused by the explosion of the digester at an anaerobic biowaste treatment plant was described by Umani Ronchi and Rossi (Ref. 196). The explosion was attributed to the probable leakage of methane through a break in the pipes that carry the gas out of the digester. Maxwell et al. (Ref. 129) described an incident in which a welder suffered severe injuries when using an oxyacetylene torch to heat the bronze end plate on a large marine water pump.

Burns. The case of a 21-year-old welder who was seriously burned on the front of his body while using an oxyacetylene torch was described by Kumar and Abraham (Ref. 112). The accident occurred as sparks from the torch fell on the safety valve of a generator in which acetylene gas was produced, causing it to melt and igniting the gas that escaped through the damaged valve. Still et al. (Ref. 178) described the case of a 38-year-old man who was standing between two railroad cars while welding the coupling mechanism with an oxyacetylene torch. When the train moved unexpectedly, the coupling penetrated his abdomen causing internal injuries and severe flame burns over 35% of his body from the welding apparatus.

Training. Wallace et al. (Ref. 208) described a case study performed by NIOSH at a welding shop in a vocational school in 1996. Numerous safety and health hazards were found including inadequate personal protective equipment, an improperly functioning ventilation system, and improperly positioned exhaust hoods.

Effects of Welding on Human Health

Respiratory Tract

Pulmonary Function. Fishwick et al. (Refs. 69, 70) measured the acute effects of welding on pulmonary function by conducting spirometric tests on welders and non-welders before, during, and after a work shift. At the end of the work shift, the welders had a significantly greater decrease in FEV₁ (the amount of air that can be forcibly exhaled in one second) than non-welders. The use of local exhaust during welding led to significantly smaller losses in lung performance 15 minutes after beginning work and at the end of the shift. The same group of welders and non-welders was examined 2 years later for signs of cumulative changes in lung function (Ref. 64). Workers who used personal respiratory protective equipment, local exhaust, or a combination of the two had a significantly smaller annual decline in both FEV₁ and forced vital capacity (FVC, a measure that is reduced in restrictive lung disease) than welders who used no protective equipment. Among workers who smoked, welders had a significantly steeper annual decline in FEV₁ than non-welders. Although management and subjects had been notified of the results of the first study (Ref. 70), few improvements to reduce fume concentrations in the welding areas had been made (Ref. 171). Sobaszek et al. (Ref. 172) administered lung tests to mild and stainless steel welders and non-welding controls before and after a work shift. At the end of the work shift, lung function was decreased in most of the tests among controls and in all tests among welders. Significant decrements in post-shift lung performance were associated with welding of stainless steel compared with mild steel and with use of SMAW compared with GTAW or GMAW. Welding stainless steel for more than 20 years was associated with greater decrements in post-shift lung function tests than was mild steel welding. Chronic effects of welding on lung function were measured in stainless steel welders using SMAW, GTAW, GMAW, and plasma welding techniques, and in controls from eight factories (Ref. 173). Welders who were engaged in GTAW had small, statistically non-significant, but consistent decrements in all of the lung function tests compared with those engaged in SMAW or GMAW or with the controls. For all welders, duration of welding experience was related to declines in expiratory flow rates. In a study of journeyman plumbers and pipefitters, Hessel et al. (Ref. 81) found lung abnormalities, as measured by spirometry, in 11.5% of the pipefitters, in 16.7% of the welders, and in 57.1% of the plumbers. In another study by the same group, boilermakers had significantly lower lung flows and volumes than welders (Ref. 80).

Asthma. In recent decades, the incidence of asthma has been on the rise throughout the industrialized world. Blanc and Toren (Ref. 24) critically reviewed studies containing risk estimates for occupational asthma and concluded that about 15% of adult asthma is associated with occupational factors. In studies by Toren et al. (Refs. 193, 194) of 683 cases of adult onset asthma in two large population centers in Sweden, welding fumes were among the industrial exposures that were significantly linked to an increased risk for the disease. Mas-trangelo examined 387 cases of asthma and found a significantly greater relative risk for occupational asthma among welders, compared with metal assembly workers. Contreras and Chan-Yeung (Ref. 48) examined six welders who had reported to a clinic with respiratory symptoms. Three of these welders exhibited asthma-like responses when they welded in the clinic using the metals that were associated with their problems at work (stainless steel in one case, galvanized steel in the other two). These reactions were attributed to non-specific irritation rather than to sensitization to specific substances in welding fumes. Vandenplas et al. (Ref. 203) examined a maintenance man who experienced an asthmatic attack when he welded aluminum but not when he welded mild steel, leading to the conclusion that aluminum may be a cause of occupational asthma. Kelesoglu et al. (Ref. 101) examined bronchial hyperreactivity and found no significant excess among welders, compared with other blue-collar workers.

Chronic Bronchitis. Bradshaw et al. (Refs. 32, 33) studied chronic bronchitis among welders and non welders in the same plant and found a significantly incidence of chronic bronchitis among welders with greater than 10 years' experience, compared to welders with less than 4 years' experience.

Magnetopneumography. Huvinen et al. (Ref. 90) investigated the relationship between the dusts retained in the lungs of workers in a stainless steel production facility, as measured by magnetopneumography (MPG), and concentrations of chromium in workplace air and in urine. The particulate lung burden did not correlate with duration of exposure, or with actual exposures to total or hexavalent chromium. There was a relationship between the lung burden of magnetizable particles and urinary chromium concentrations. Nakadate et al. (Ref. 135) measured lung function and iron deposits in the lungs of welders before and after a 5-year period in which engineering and industrial hygiene practices were instituted that substantially reduced exposures to welding fumes. At the start of the study, they observed a deficit in pulmonary function, indicative of obstructive changes in the lung, that correlated with accumulation of welding fumes in the lungs, measured using MPG. Five years later, after

many improvements had been made in the air quality in the plant, the lung burden of magnetizable particles had significantly decreased (Ref. 136), but this did not lead to an improvement in their pulmonary function.

Pneumoconiosis. Steurich and Feyerabend (Ref. 177) described a welder who experienced fatigue and difficulty breathing. X-rays revealed small nodular opacities scattered throughout the lungs, and lung tissue biopsy revealed iron deposits and areas of fibrosis. In an unusual case of pneumoconiosis, described by Kinoshita et al. (Ref. 108), a single, poorly defined, solitary mass, 3 cm in diameter, with large quantities of iron was found in a 60-year-old man with 25 years' welding experience. This solid mass was diagnosed as pneumoconiosis and not lung cancer. Yamada et al. (Ref. 211) described an unusual medical treatment for siderosis in a 42-year-old welder who was admitted to the hospital complaining of a dry cough. A total of 911.7 mg of fume particles were washed from his lungs by bronchopulmonary lavage with over 13 liters of saline solution.

Medico-legal investigations of two cases of pulmonary disease occurring in welders determined that they were not related to occupational exposures. In France, Charpin et al. (Ref. 41) examined the case of a man who sought medical attention in 1992 after suffering recurrent sinusitis, bronchitis and purulent pleurisy. These conditions were attributed to bronchiectasis (chronic inflammation of portions of the bronchial wall) and were judged to be unrelated to his occupational exposures as a welder. In Germany, Strohbach et al. (Ref. 180) evaluated the case of a 46-year-old welder who suffered from an acute interstitial lung disease, with symptoms of dry cough, night sweats and chills, and chest pains with breathing difficulties that worsened at work. This condition improved after treatment with corticosteroids, but he developed pain in his joints, knees and fingers and was diagnosed with CREST syndrome (a limited form of scleroderma).

Case Reports. Tojima et al. (Refs. 192, 7) described the case of a 61-year-old welder with a 32-year welding career who developed symptoms of metal fume fever within hours after welding galvanized steel. Clinical examination and chest X-rays indicated he had acute chemical pneumonitis, which the authors attributed to exposure to ZnO fumes. Barbee (Ref. 16) described the case of a 43-year-old maintenance worker who developed pneumonitis with pulmonary edema 12 hours after cutting a galvanized steel grating with an oxyacetylene torch without using a respirator. His exposure was re-created at his place of employment, and air sampling revealed that he may have been exposed to levels of cadmium twice the OSHA PEL and to levels of zinc over 20 times the PEL. Bousova-Kostelnikova (Ref. 31) described an incident in

which two welders were affected by fumes while working in a newly-built storage tank. One welder used an oxyacetylene torch and the other used SMAW. No mechanical exhaust systems were used, and neither welder was equipped with a respirator. About 10 hours after finishing work, one of the welders developed difficulty breathing and was diagnosed with pulmonary edema. The second worker was less severely affected and developed symptoms of a dry, irritating cough, general malaise, and headache. The cause of these conditions was deemed to be exposure to nitrogen dioxide with a possible contribution by ozone.

Cancer

Lung Cancer. In a study by Becker (Ref. 18), lung cancer was non-significantly elevated among welders compared with machinists. The presence of seven cases of mesothelioma in the group of welders led the author to conclude that the observed excess of cancer mortality among welders in his study was predominantly due to asbestos exposure. Van Loon et al. (Ref. 201) compared occupational exposures to asbestos, paint dust, polycyclic aromatic hydrocarbons, and welding fumes among incident cases of lung cancer and in a representative sample drawn from the same population as the lung cancer cases. Exposure to asbestos was highly correlated with increased risk for lung cancer. There was an elevated risk for lung cancer associated with welding fumes, but not after the data were adjusted for exposure asbestos, paint dust, and polycyclic aromatic hydrocarbons. The authors estimated that 11.6% of lung cancer in men is attributable to occupational exposure to asbestos. These investigators also found that men with the highest level of education had a significantly lower risk for lung cancer compared with men with the least education. Jockel et al. compared occupational exposures of German men newly diagnosed with lung cancer with those of a matched group of controls (Ref. 99). The relative risks for lung cancer were significantly increased with exposure to asbestos and with ever having held the job title of welder. There was, however, a negative exposure-response relationship for welding: exposure to welding fumes for less than 1,000 hours was associated with a higher relative risk for lung cancer than was found for exposures greater than 6,000 hours. In a pooled case-control study, Ahrens et al. (Ref. 4) found a significantly elevated relative risk for lung cancer among welders in western Germany (the former Federal Republic of Germany), but not eastern Germany (the former German Democratic Republic). Welding mild steel for more than 30 years was also associated with increased risk for lung cancer in western Germany. Teschke et al. found an elevated relative risk for

mesothelioma among welders in a case-control study conducted in British Columbia, but this result was not statistically significant (Ref. 188). Milatou-Smith et al. (Ref. 132) compared lung cancer mortality between welders of stainless steel, who were exposed to relatively high levels of Cr(VI), and railway repair workers, who had low levels of exposure to Cr(VI). The stainless steel welders had a greater, but non-significant, relative risk of death from lung cancer, and the authors concluded that their study supports the classification of hexavalent chromium as a carcinogen. A letter to the editor (Ref. 8) disputed the contribution of nickel and hexavalent chromium to lung cancer in welders, citing a large European study (Ref. 165) that showed a statistically significant increased mortality from lung cancer among welders of mild steel but not stainless steel. Matos (Ref. 128) found an elevated, but non-significant relative risk for lung cancer among welders in a case-control study in Argentina. In another study of lung cancer in Argentina, Pezzotto and Poletto found that welders had a significantly elevated risk for squamous cell cancer of the lung, but a slightly increased relative risk for all lung cancers among welders was not statistically significant (Ref. 149). A hospital-based case-control study in Belgium found that exposure to chromium for longer than 30 years was associated with a significant excess risk for lung cancer (Ref. 60). In a study of causes of death among ironworkers, Stern et al. (Ref. 176) found that welders had significantly greater risks of death from all cancers and from falls, compared with the general population, and a non-significant excess risk of death from lung cancer. Danielsen (Ref. 52) investigated lung cancer among Norwegian shipyard welders who had been examined for siderosis 17 years earlier. No relationship was found between having been diagnosed with siderosis and mortality from lung cancer.

A 68-year-old man who had worked for 4 years as a full-time welder and for 30 years as a part-time welder (Ref. 79) had chronic inflammation and severe fibrosis of the lungs. He subsequently developed epidermoid cancer in the affected area of the lungs. Liu et al. (Refs. 121, 122) found that mutations in the P53 suppressor gene isolated from lung tumor specimens from workers who had pneumoconiosis associated with exposure to silica, asbestos, or welding fumes differed from those in lung cancer specimens taken from persons in the general population. They concluded that these differences might indicate that DNA damage in lung tumors associated with exposure to silica, asbestos, or welding fumes may arise by a different mechanism than do tumors associated with other causes such as tobacco smoke.

Cancers at Other Sites. Andersen et al. (Ref. 6.) conducted a comprehensive survey of cancer incidence rates between 1970 and 1990 among all adults who had re-

sided in four Nordic countries in 1970. They found a small but significant increase in the incidence of cancers of all types among male welders, compared with the male population of Finland, Norway, and Sweden combined. Cancers of the gall bladder, lung, pleura, kidney, and urinary bladder were significantly elevated among the welders. In a continuing study of cancer mortality among welders in Germany, Becker (Ref. 18) found that welders had a significantly elevated relative risk of dying from cancer of all causes, compared with a control group of machinists. Welders who used SMAW, but not other processes, had significantly higher mortality from brain cancer, compared with the general population. In a case-control study in British Columbia, Teschke et al. (Ref. 189) found a non-significant elevation in the risk for nasal cancer and no increased risk for bladder cancer among welders. Gustavsson et al. (Ref. 76) conducted a community-based case-control study of the incidence of cancer of the oral cavity, pharynx (throat), and esophagus in two densely populated regions of southern Sweden. Statistically significant risks of pharyngeal cancer and laryngeal cancer were associated with more than 8 years of exposure to welding fumes. Exposures to welding fumes were not associated with a risk for cancer of the oral cavity or esophagus. In a case-control study in Northern Sweden, Schildt et al. (Ref. 162) observed a non-significantly increased risk for oral cancer among welders. A significant excess risk for pancreatic cancer was found in the occupational group of plumbers and welders in a study by Ji et al. (Ref. 97). Fabbro-Perray et al. found that daily exposure to welding was associated with a significantly elevated risk for non-Hodgkins lymphoma (Refs. 65, 66). Holly et al. (Ref. 87) found no association between occupational exposures and non-Hodgkins lymphoma in HIV-positive men. Among HIV-negative men, a significantly increased risk for the disease was associated with certain chemicals, but not with welding and soldering. Welders were found to have a significantly increased risk for multiple myeloma in studies by Costantini et al. (Refs. 49, 50).

A welder with recurrent dermatitis and keratosis had several squamous cell carcinomas removed from his face. This man, who had been sensitive to ultraviolet light since childhood, was advised to discontinue welding (Ref. 147). Another welder, who developed a basal cell carcinoma on an exposed area of his upper chest, also had had numerous incidences of erythema from welding and sunburn. Unlike the case described above, he had no keratoses on exposed areas of his skin (Ref. 59). Olshan et al. (Ref. 146) studied neuroblastomas in children with relation to their fathers' occupations. Although the risk for neuroblastomas was significantly correlated with paternal exposure to EMFs, there was no association between neuroblastoma risk and welding,

which is considered one of the occupations most highly exposed to EMFs.

Metal Fume Fever

Van Pee et al. (Ref. 202) described a typical case of metal fume fever in a 23-year-old man who became ill 3 hours after completing a work shift in which he had been welding galvanized steel without wearing a respirator.

Kuschner et al. (Ref. 115) found that the concentrations of the cytokines interleukin-1 (IL-1), IL-6, IL-8, and tumor necrosis factor (TNF), but not the numbers of leukocytes, were significantly elevated in BALF collected from 15 human volunteers 3 hours after inhalation exposure to zinc oxide (ZnO) fumes. At 3 hours after exposure, Neutrophils were significantly higher in bronchoalveolar lavage (BAL) fluid collected at 20 hours than in that collected at 3 hours. Exposure of volunteers to magnesium oxide caused no significant changes in the concentrations of any of the four cytokines studied (IL-1, IL-6, IL-8, and TNF) or in the numbers of leukocytes in BALF (Ref. 116).

Effects on the Eye

Effects on the Retina. Lesions of the retina were described in welders by four investigators (Refs. 179, 56, 2, 111). Stokkermans and Dunbar (Ref. 179) described three welders diagnosed with solar retinopathy, a condition that usually develops from gazing at the sun. All of the welders had good visual acuity, but two of them had visual field defects, such as blind spots. Denk et al. (Ref. 56) described the case of a 38-year-old man who developed arc welding maculopathy, attributed to exposure to optical radiation, while welding for 2 hours without proper eye protection. Seventeen welders with central serous chorioretinopathy (a lesion of the retinal pigment epithelium) were described by Adelberg (Ref. 2) who postulated that the lesions originated as welding arc maculopathy. Subretinal neovascularization, a condition that accounts for 10% of age-related macular degeneration, was observed in a welder by Kozielec and Smith (Ref. 111).

Eye Protection. Daxer et al. (Ref. 53) evaluated the effectiveness of an eye drop preparation, commercially available in Europe, designed for protection against both solar and artificial UV radiation. They found that a liquid layer of about 10 μm , which corresponds to the thickness of the film of tears normally coating the human eye, allowed the transmission of about 25–50% of the UV-C radiation (100–280 nm) and more than 90% of the UV-B, UV-A, and visible light (290 and 500 nm). The investiga-

tors calculated that the eye drops would provide about 35% protection against photokeratitis during unprotected exposure to the welding arc.

In a survey of the use of eye protection by welders in Lagos, Nigeria, Oduntan (Ref. 144) found that proper eye protection was worn by only 44% of 339 welders, and that the use of proper eye protection was not consistent, even among some who usually wore goggles. The inadequate safety practices among Nigerian welders was attributed in part to the lack of understanding of the ocular hazards associated with welding and in part to the lack of safety standards for welders in Nigeria.

Effects of Aluminum

In a cross-sectional study of cognitive function in asymptomatic welders with up to 23 years' experience performing GMAW of aluminum, Akila et al. (Ref. 5) found that aluminum exposure was associated with detrimental effects in certain cognitive functions but had no effect on verbal comprehension. Similarly, immediate visual memory or basic visuoperceptual processes were unimpaired, although processes that involve holding a complex design in memory and that require reproducing that design were impaired. Kilburn (Ref. 104) evaluated the published data on the effects on the brain of occupational exposure to fine aluminum particles. She noted that commercial aluminum is frequently alloyed with copper, manganese, or zinc, and it is therefore possible that aluminum welders may have significant exposures to manganese which has some effects that are similar to those that have been observed in aluminum workers in some studies.

Effects of Manganese

Sato et al. (Ref. 161) described a welder with signs of parkinsonism which was diagnosed as manganese poisoning based on high concentrations of manganese in serum and urine and on cranial magnetic resonance imaging (MRI) which showed hyperintense signals indicative of manganese deposition. The size and density of the MRI signals were reduced after 10 months. Arjona et al. (Ref. 13) described a construction worker who was experiencing mental confusion, sudden unprovoked falls, and had mild rigidity and tremor in both arms. Cranial MRI revealed images indicative of manganese deposition and his urinary manganese concentration was elevated. Ten months after stopping work, his urinary manganese concentrations were normal, his physical condition improved, and an MRI scan was normal. Kim et al. (Refs. 105, 106) described a welder with signs of parkinsonism. MRI showed the high signal intensities in the brain that