

Effects of Welding on Health, XI



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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, XI

Prepared for
AWS Safety and Health Committee

Research performed by
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Abstract

This literature review, with 171 citations, was prepared under contract to the American Welding Society for its Safety and Health Committee. The review deals with studies of the fumes, gases, radiation, and noise generated during various welding processes. Section 1 summarizes recent studies of occupational exposures, Section 2 contains information related to the human health effects, and Section 3 discusses the effects of welding on animals and cell cultures.



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Foreword

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

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

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Glossary*

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

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

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Introduction

The health of workers in the welding environment is a major concern of the American Welding Society. To stay abreast of this subject, the health literature is periodically reviewed and published in the report *Effects of Welding on Health*. Ten volumes have been published to date; the first covered data published before 1978, while the remainder covered 1 to 3 year periods between 1978 and December, 1994. The current report includes information published between January 1995 and December, 1996. It should be read in conjunction with the previous volumes for a comprehensive treatment of the literature on the *Effects of Welding on Health*. Included in this Section 1 of this volume are studies of the characteristics of welding emissions that may have an impact on the control technologies necessary to protect the welder. In keeping with previous volumes, health reports and epidemiological studies of humans are discussed in Section 2 and organized according to the affected organ system. Research studies in animals are discussed in Section 3.

Many of the studies on the effects of welding on health published during the current report period focused on matters that have been explored in the older literature. The question of whether or not welding causes a decrease in the function of the lungs or causes an increased incidence of pulmonary diseases such as bronchitis continues to be explored. Investigations of the association of asthma with welding increase in number as the prevalence of both occupational and non-occupational asthma increases worldwide in industrialized countries. As in the past, attention is focused on the incidence of lung cancer in welders and the contribution of the potential carcinogens nickel and chromium encountered in stainless steel welding to the incidence of the disease. Current studies do not indicate that stainless steel welders are at a greater risk for developing lung cancer than are mild steel welders. However, studies in laboratory rats showed that stainless steel welding fumes are cleared more slowly from the lungs than are mild steel welding fumes. Studies from Ukraine continue to focus on the deposition and potential deleterious effects of iron in organs other than the lung. While, as in the past, no studies focused on health effects of welding in women due to their small representation in the trade, two articles addressed the question of ergonomic, safety, and sociological stresses faced by female construction workers.

Executive Summary

Health and Safety

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

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

Effects on the Respiratory Tract

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

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

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

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

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

Cancer

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

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

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

Health Effects Related to Duration of Welding Experience

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

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

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

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

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

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

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

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

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

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

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

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

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

Technical Summary

The Exposure

Fume Composition

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

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

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

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

gas of argon containing 5% CO_2 and 2% O_2 and an outer shield gas of either argon with 300 ppm nitric oxide or trace quantities of ethylene.

Analytical Methods

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

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

Workplace Exposures

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

Hori et al. (Ref. 71) measured concentrations and size distributions of welding fume samples collected at 20 workplaces in Japan. Average fume concentrations were 11.3 mg/m^3 in personal samples, 0.4 mg/m^3 in general area samples, and 46.8 mg/m^3 in source samples. The authors concluded that neither general area nor point source sampling is a reliable substitute for personal monitoring.

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

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

Liu et al. (Ref. 92) measured breathing zone lead concentrations and particle size distributions in welding fumes generated by high voltage welding during lead battery manufacturing. The mean concentration of lead in the welding fumes was 26 µg/m³ but particles greater than 10 µm in diameter accounted for 71% of the mass of the samples.

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

Electromagnetic Radiation

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

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

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

Electromagnetic Fields

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

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

Hygiene and Work Practice

Protective Gear and Equipment. Liu et al. (Ref. 93) measured metal fume concentrations inside and outside the welding helmet in the personal breathing zones of 20 welders performing electric arc welding on galvanized mild steel using a cellulose-covered electrode. The mean ratio of inside-to-outside iron concentrations was 0.9; the median ratio was 0.96 which indicated that the welding helmet provides ineffective attenuation of exposure to welding fumes. Using a respiratory plethysmograph and a mass spectrometer, Stromberg (Ref. 141) developed a method for measuring the volume of CO₂ in the dead space of a welding visor and the fraction of CO₂ in the inspired air of welders wearing visors. The mean inspired CO₂ concentrations for subjects wearing the visor were higher than the TLV.

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

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

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

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

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

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

Effects of Welding on Human Health

Respiratory Tract

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

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

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

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

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

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

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

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

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

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

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

Cancer

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