

Effects of Welding on Health, VI



American Welding Society



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Effects of Welding on Health—VI

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An updated (July 1984-December 1985) literature survey and evaluation of the data recorded since the publication of the first report (1979). This series of reports is intended to aid in the understanding of the health effects of welding.

Performed by:

Winifred Palmer

May, 1987

Abstract

This literature review with 172 citations has been prepared for the Safety and Health Committee of the American Welding Society to provide an assessment of current knowledge of the effects of welding on health, as well as to aid in the formation of research projects in this area, as part of an ongoing program sponsored by the Society. Previous work has included studies of the fumes, gases, radiation, and noise generated during various arc welding processes. Referenced materials are available from Tracor Jitco.

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Safety and Health Committee
American Welding Society
550 N.W. LeJeune Road, P.O. Box 351040
Miami, FL 33135

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American Welding Society,
550 N.W. LeJeune Road, P. O. Box 351040, Miami, Florida 33135

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<i>D.W. Walsh</i>	California Polytechnic State University

**Advisor*

Foreword

(This Foreword is not a part of *Effects of Welding on Health VI*, 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 ongoing program sponsored by the Committee. Previous work included studies of the fumes, gases, radiation, and noise generated during various forms of arc welding. Conclusions based on this review and recommendations for further research are presented in the introductory portions of the report. Section 1 summarizes recent studies of the occupational exposures, while Section 2 contains information related to the human health effects of exposure to byproducts of welding operations. Section 3 discusses studies of the effects of welding emissions on laboratory animals and in vitro cell systems. Reference materials are available from Tracor Jitco, Inc.

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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**. Five volumes have been published to date; the first covered data published before 1978, while the latter four covered time periods between 1978 and June, 1984. The current report includes information published between July, 1984 and December, 1985. 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 volume are studies of the characteristics of welding emissions that may have an impact on the control technologies necessary to protect the welder (Section 1). In keeping with previous volumes, the health studies are organized according to the affected organ system. The respiratory tract, the primary route of exposure to welding emissions, is also a major target organ of a number of components of these emissions. Acute (e.g., metal fume fever, cadmium poisoning) as well as potential chronic respiratory effects (e.g., emphysema, cancer) of welding emissions are of concern. However, chronic effects are not as well defined or understood and whether there is an excess risk of cancer from these exposures has not been established. Continued research in the form of epidemiologic studies, investigations with laboratory animals, and in vitro genotoxicity studies will help to resolve this question.

Executive Summary

Research on the health effects of welding continues to focus on the effects of chronic exposures to welding fumes on the respiratory tract. A problem inherent in much of this research is the difficulty in conducting studies on homogeneous populations due to the variability in welding processes and in working conditions. With time, this problem has become better understood, and today many investigators are attempting to relate their research results to exposures during specific welding processes.

The Respiratory Tract

Abnormal shadows are often seen in chest X-rays of welders. These shadows represent deposits of particles from welding fumes in the lungs (referred to as *arc welders' pneumoconiosis*). Normally these shadows are not associated with loss of lung function or diseases of the respiratory tract and, in some cases, they disappear after affected welders are removed from further exposure to the fumes.

Several studies performed during this report period indicate that welders exhibit a reduction in the volume of air that can be inhaled or expelled from the lungs (as measured by lung function tests). Other studies found no changes in lung capacity and attributed the absence of effects on lung function among welders to good ventilation in the work area or to the use of gas tungsten arc welding (GTAW) which generates little fume compared with most other commonly used welding methods.

The association of welding with bronchitis remains unclear. An excess of bronchitis was observed in welders in nine studies published during this report period. In three studies, the incidence of bronchitis could not be separated from the use of tobacco. One investigator suggested that smoking and welding may act synergistically in the induction of bronchitis. Bronchitis was observed more frequently in shielded metal arc welders than in gas metal arc welders, which supports the supposition that bronchitis may be related to the intensity of welding exposure.

The question of whether welders have an increased risk of lung cancer remains unresolved. In the past, results of cancer epidemiology studies of welders have been inconsistent, with several studies suggesting that the incidence of lung cancer may be elevated

among welders. Nickel and hexavalent chromium, potential human carcinogens, may be present in significant quantities in stainless steel welding fumes. Past studies neither refuted nor supported the hypothesis that the lung cancer risk is elevated among stainless steel welders. Investigations currently in progress are focusing on populations exposed to welding fumes with known or suspected carcinogens. The results of these studies should begin to provide a much needed answer to the question of whether cancer in welders is associated with exposures to specific welding processes.

Severe acute respiratory distress can result from highly toxic chemicals, such as phosgene, that arise from interactions of degreasing agents such as 1,1,1-trichloroethane and ultra-violet light. Because of this, vapors from degreasing agents or paints can present a hazard in welding shops. Two incidents were described in which welders may have suffered respiratory distress from gas metal arc welding (GMAW) in an area where degreasing agents were used.

Biological Monitoring of Exposure to Welding Emissions

Industrial hygiene measurements of airborne concentrations of contaminants are exceedingly important for controlling exposures to welding emissions. However, they do not take into account variations in physiology and personal habits among workers and thus, do not reflect the amount of material actually taken up by the body from the work environment. In conjunction with determination of airborne exposure levels, biological monitoring, or the measurement of chemicals or their metabolites in the body fluids, may provide a means for estimating the actual dose of contaminants taken up by the body.

As in past years, considerable effort was expended during the current report period to identify substances that can be monitored in this way. The feasibility of applying biological monitoring techniques to elements such as chromium, nickel, lead, cadmium and manganese was examined. Blood and urine chromium levels, but not nickel levels, were found to be useful for estimating exposure to fumes generated by welding of stainless steel.

Technical Summary

The Exposure

Fumes

The concentration of solids in welding aerosols varies with the welding process, electrode, base metal, current, voltage, and base metal coatings. Shielded metal arc welding (SMAW) and flux cored arc welding (FCAW) produce more fumes, while GTAW produces much less fumes than other welding and allied processes. Because of its potential carcinogenicity to humans, the concentration of hexavalent chromium in fumes is important and has received a great deal of attention. The ratio of hexavalent to total chromium is much higher in fumes generated by SMAW and FCAW than in those generated by GMAW and GTAW.

Standardized methods for fume sample collection in laboratory settings and in the work place are important for providing realistic appraisals of risk and enabling comparison of results between laboratories. New standards for collecting samples of airborne particulates in the breathing zone and work area (Ref. 6) and for determination of fume generation rates and total fume emissions (Ref. 5) have been published by the American Welding Society.

The Swedish fume box for measuring fume emission rates (FER) generated by SMAW electrodes was modified by the British Welding Institute to enable determination of FER's from other welding processes (Refs. 94 and 99). FER's of carbon arc gouging, FCAW, GMAW, and GTAW, determined by the modified fume box, were generally within ranges found by other techniques (Ref. 94). Based on data obtained from fume box determinations, the British Welding Institute has established a computerized data base for storage and retrieval of data applicable to emissions from all arc welding processes (Ref. 100).

Using an aerosol photometer to obtain rapid measurements of welding fume concentrations at one second intervals, Glinsmann and Rosenthal (Ref. 46) showed that fume generation during welding is not uniform and continuous but rather there are wide and instantaneous fluctuations in fume concentra-

tion. Such fluctuations did not occur during oxyacetylene cutting.

The chemical composition of fumes may vary with fume generation rate as well as with the formulation of the electrode. Tandon et al. (Ref. 151) showed that the iron content of the fumes was directly proportional, and the fluoride content was inversely proportional, to fume generation rates. A strong correlation between the ratio of water-soluble hexavalent chromium to total chromium in the fume and the concentration of sodium and potassium in the flux was observed.

Substitution of sodium silicate for potassium silicate in basic electrode coatings reduced fume production by twenty five percent (Ref. 86). Limpel et al. (Ref. 81) found that the quantity of water-soluble, but not total fluorine, was considerably greater in fumes generated by electrodes containing potassium silicate than in those with sodium silicate. Other experiments showed that quantities of hydrogen fluoride (HF) and silicon tetrafluoride (SiF₄) increased with the concentration of silica (SiO₂) in the electrode coating, but only HF increased with the moisture content (Ref. 165). The levels of hexavalent chromium in the fumes were directly dependent on the quantities of sodium silicate, potassium and calcium levels in the electrode coating (Ref. 86).

Thorne and Hewitt (Ref. 157) showed that fume formation during brazing Ag-Zn-Cd-Cu alloys is related to the amount of bubbling in molten brazing flux. They concluded that exposures to cadmium fumes can be reduced by raising the pH of the fluoro-borate flux to reduce hydrogen gas formation and by lowering the concentrations of compounds (boric acid and potassium hydrogen fluoride) in the flux that are largely responsible for bubble formation.

The issue of which technique is best for measuring hexavalent and total chromium in fumes remains controversial. Dare et al. (Ref. 29) criticized the interlaboratory round robin validation study of the Blakely and Zatka method for hexavalent chromium determination (Ref. 22) for not taking into account the short-lived hexavalent chromium species detected in fresh GMAW fumes collected by water impingement (Refs. 53 and 156). Zatka (Ref. 166) suggested that this hexavalent chromium species derives from a

chemical reaction within the impingement collector fluid rather than by reactions within the fume solids. Zatzka also modified his initial method (Ref. 22) for hexavalent chromium determination to suppress the small amount of hexavalent chromium that can form during digestion of trivalent chromium in hot alkaline solutions.

Gases

Ozone, carbon monoxide, carbon dioxide and nitrogen oxides are the principal gases generated by welding. The quantities of nitrogen oxides, carbon monoxide, carbon dioxide and methane released during SMAW varies considerably with the electrode (Ref. 158). Nemcova (Refs. 108 and 109) reported finding high concentrations of nitrogen oxides and ozone during plasma arc cutting of steel, aluminum, and copper. Nitrogen oxide levels were relatively high during argon-shielded GTAW of copper and aluminum.

Radiation

Eriksen (Ref. 37) demonstrated that a short burst of high levels of ultraviolet (UV) radiation occurs during the initial phase of arc ignition during GMAW of aluminum. The intensity of this UV overshoot was more than ten times that of the UV light emitted when the arc was burning "smoothly". Because of the intensity of the UV overshoot, the unprotected eye at a distance of 0.5 meters may suffer welder's flash after exposure to radiation from only one ignition.

Production Coatings

Organic compounds, metal oxides, and toxic gases may be released when welding metals coated with paints or primers. Moreton (Ref. 98) and McMillan (Ref. 91) reviewed the hazards of welding coated or contaminated surfaces. Moreton described and evaluated standard procedures recommended by representatives of the welding and paint industries in 1964 and 1968 for assessing the toxicity of fumes released from flame cutting or welding of primed metals. The

need for new standards which would allow realistic appraisal of the hazards associated with welding and cutting of primed materials was stressed (Ref. 97).

Degreasing Agents

Fumes from degreasing agents or paints can present a major hazard in welding (Refs. 9 and 91). Chlorinated hydrocarbons such as trichloroethylene, perchloroethylene and 1,1,1-trichloroethane can decompose in the presence of ultraviolet radiation into highly toxic compounds such as phosgene and dichloroacetyl chloride.

Two incidents were described in which photochemical decomposition products resulting from reaction of degreasing agents with UV light produced by GMAW may have been the cause of significant respiratory effects. In the first, eleven welders complained of coughing, breathlessness, chest tightness, and irritation of the throat and eyes while performing GMAW, but not SMAW. A degreasing operation was conducted on the shop floor in the vicinity of the welders where there was good general ventilation. Ambient concentrations of trichloroethylene and trichloroethane in the work environment were too low to have caused noticeable health effects and phosgene could not be detected. Removal of the GMAW operation to an area distant from sources of chlorinated hydrocarbons successfully resolved the problem (Ref. 135).

In the second incident, a Swedish welder developed pulmonary edema after performing GMAW of mild steel in an environment containing high levels of 1,1,1-trichloroethane. Although 0.4 ppm ozone was detected when welding under the same conditions in a glove box, insufficient concentrations of toxic gases were detected when welding in an open room similar to the one used by the affected welder to have accounted for the pulmonary edema. (Ref. 56).

Noise

Impulse noise is more harmful to hearing than continuous steady state noise of the same energy level. Tests performed at a shipyard plate welding workshop indicated that grinding and carbon arc work do not produce impulse noise, while welding (especially GMAW) had the highest impulse noise levels (Ref. 78).

Effects of Welding on Human Health

Respiratory Tract

The physiological consequences of pneumoconiosis ["the accumulation of dust in the lungs and the tissue reaction to its presence", (Ref. 64)] are related to the fibrogenicity and amount of deposited dust. Several investigators studied the extent of fibrosis in the lungs of subjects with arc welders' pneumoconiosis. Most found that scar tissue formation was minimal, that fibrosis rarely progressed into a disabling condition, and opacities seen in chest X-rays of those with pneumoconiosis sometimes regressed with time after cessation of welding exposures. Such results indicate that arc welders' pneumoconiosis is, for the most part, a benign condition (Refs. 130, 131, 137, 142, 144, and 147).

The effects of welding on pulmonary function were examined in twelve studies. Half of these found no substantial abnormalities (Refs. 85, 139, 142, 171, 130, and 136). In two studies (Refs. 136 and 139), the absence of effects on pulmonary function among welders was attributed to good ventilation in the work area. A third study (Ref. 171) attributed the overall good health status and lack of pulmonary function abnormalities to the use of GTAW which generates little fume compared with most other commonly used welding methods.

An age-related reduction in pulmonary function among welders was found by Zober and Weltle (Ref. 172). Mao (Ref. 88) reported an association between pneumoconiosis and abnormal pulmonary function tests, but three other investigators found no such correlation (Refs. 85, 142 and 172). Mur et al. (Refs. 105 and 106) reported that shielded metal arc welders had significant reductions in pulmonary function compared with gas metal arc welders. In some cases, welders who worked in confined spaces had reduced lung function compared with those in well ventilated areas. Schneider et al. (Ref. 137) noted a reduction in pulmonary function which appeared to be related to the duration of welding exposure.

An association between exposure to welding emissions and bronchial hyperreactivity was suggested by Barnhart et al. (Ref. 15), who observed a decrease in pulmonary function in welders only after challenge with bronchodilators. Inconsistencies between studies may be related, in part, to the inability of pulmonary function tests to routinely detect early changes in the lungs.

In general, this research suggests that welding may reduce selected parameters of pulmonary function and that fume emission rates and ventilation in the work area are influential factors.

An elevated incidence of bronchitis was found in welders in nine studies. Zober et al. (Refs. 171 and 172) attributed bronchitis solely to tobacco use. A substantially elevated frequency of bronchitis among welders was also reported by Mal'ik et al. (Ref. 85). However, in that report, no attempt was made to account for the high rate of tobacco use among the cohort. That smoking and welding may act synergistically in the induction of bronchitis and reduction of pulmonary function was suggested by Schneider et al. (Ref. 137) and Mur et al. (Refs. 105 and 106), respectively. Mur et al. (Refs. 105 and 106) observed bronchitis more frequently in shielded metal arc welders than in gas metal arc welders, which implies that bronchitis may be related to the type and extent of exposure. Whether or not welding alone can produce bronchitis remains unclear.

Cancer

Langard and Stern (Ref. 80) reviewed twenty one cancer epidemiology studies of welders published in the international literature before 1984. Of these, five studies showed a significantly elevated cancer risk among welders, and only one examined a cohort of stainless steel welders. Stainless steel welding fumes contain hexavalent chromium and nickel compounds which may be carcinogenic. Because of this, it has been suggested that epidemiologic studies focus on stainless steel welders (Ref. 80).

Two epidemiologic studies of nickel-and chromium-exposed welders were published in 1985. Using a case-referent approach, Gerin et al. (Ref. 45) showed that persons with excessive nickel and chromium exposures exhibited a threefold excess of lung cancer while there was no statistically significant association between nickel exposure and the risk of cancer development in other organs. A retrospective epidemiologic study of the cancer risk from exposure to nickel and chromium in 1221 welders employed in 25 German factories was conducted by Becker et al. (Ref. 18). They found that the cancer mortality rate was significantly increased in welders, but the number of cancer cases was too small to enable calculation of cancer rates in specific organs.

Negative results were obtained in three cancer mortality studies. Milham (Ref. 92) determined the number of deaths from cancer among the death records of 486,000 adult men filed in the State of Washington between 1950 and 1982. A significant increase in the

cancer incidence was not observed among the welders. Newhouse et al. (Ref. 110) found no significant increases in the mortality rates from cancer among 1027 welders who worked in a British shipyard between 1940 and 1968. Similarly, Esnault et al. (Ref. 38) found no significant excess of deaths from cancer among 100 welders who worked at a French shipyard for a period of 16 years. A possible combined effect of exposure to polycyclic aromatic hydrocarbons and welding emissions was found by the United Automobile Workers Union. A two- to five-fold excess in the number of deaths from cancer of the lung, digestive organs, testes and leukemia was observed in millwrights and welders exposed to fumes from welding and coal tars (Ref. 138).

Mastromatteo (Ref. 90) reviewed the epidemiologic studies of nickel published since 1977 and concluded that there was insufficient evidence to associate nickel with respiratory cancer in nickel welders. In his review of published epidemiologic and animal studies of the carcinogenicity of iron oxide, Stokinger (Ref. 147) concluded that iron oxides are not carcinogenic.

Metal Fume Fever

Metal fume fever is caused by excessive inhalation of metal oxide fumes. Fever, chills, general malaise, joint pains, cough, sore throat, chest tightness and fatigue usually appear four to twelve hours after exposure and last from one to two days. Diagnosis of metal fume fever is often difficult because its symptoms resemble those of a number of upper respiratory tract illnesses. Barnhart and Rosenstock (Ref. 14) reported a case of a welder with cadmium poisoning that was misdiagnosed as metal fume fever. Because of the potential seriousness of cadmium poisoning, they emphasized that possible exposure to cadmium fumes should be considered whenever patients show symptoms of metal fume fever.

Effects on the Ear and Hearing

Impulse noise may be more damaging to hearing than continuous noise of the same energy level. Platers and welders exposed to impulse noise developed hearing loss with shorter exposures than did workers in a cable factory exposed to continuous noise (Ref. 87).

Effects on the Eye and Vision

Photokeratitis (welder's flash) is a painful inflammation of the cornea which results from exposure to ultraviolet radiation. Symptoms do not appear until several hours after exposure. Millodot and Earlam (Ref. 93) found the cornea to be less sensitive to touch during the first several hours following exposure to radiation from the welding arc.

Pterygia, membranous growths which extend across the outer eye from the conjunctiva to the cornea, are thought to be caused by ultraviolet radiation. Karai and Horiguchi (Ref. 71) found a significant relationship between the duration of employment as a welder and the incidence of this lesion.

Two studies suggested that exposure to the welding arc accelerates changes in the eye which normally occur with aging. The first found changes in the number of cells in the corneal endothelium. These changes have no known effect on corneal function (Ref. 72). The second study indicated that welding may accelerate the formation of senile cataracts (Ref. 84). Conversely, Dvorak et al. (Ref. 34) found no changes in the lens that could be attributed to shielded metal arc welding.

The time required for restoration of visual acuity following exposure to strong light was reported by Dobromyslov (Ref. 31) to be significantly decreased in gas metal arc welders whereas no such changes were observed by Gos et al. (Ref. 52). The latter investigators noted that welders were better able to differentiate shapes at minimum illumination than were controls.

Sensitivity to Fume Components

Four cases of severe contact dermatitis, with itchy rashes on the ankles, hands and forearms, severely fissured lip lesions, bloody nasal discharge, muscle and joint pain, and inflammation of the esophagus, were related to the frequent and intensive use of high-chrome welding rods (Ref. 102).

Effects on the Musculoskeletal System

Herberts et al. (Ref. 60) showed that welders had a significantly greater incidence of shoulder tendonitis than did controls. Both Herberts et al. (Ref. 60) and Stone (Ref. 148) reported that static work may entail

a higher risk for chronic shoulder pain and that the most common repetitive strain injury among welders is caused by static load strain.

Effects on the Urogenital Tract

Cadmium can cause kidney damage which is first manifested by urinary excretion of serum proteins (proteinuria). Chiesura et al. (Ref. 24) found that blood and urine cadmium levels in 16 cadmium-exposed persons were related to the duration and severity of exposure. One case of nephropathy was attributed to cadmium exposure.

Elinder et al. (Ref. 35 and 36) characterized the nature of renal effects in 60 cadmium-exposed workers. Urinary beta-2-microglobulin concentrations correlated well with levels of urinary cadmium and with the estimated cumulative cadmium dose. Cadmium-exposed workers with a history of kidney stones had significantly higher urinary cadmium levels and tended to have higher urinary beta-2-microglobulin levels than those with no history of stones. The low molecular weight protein, urinary beta-2-microglobulin, remained elevated in most subjects even six years after exposure had ceased, indicating that cadmium may cause irreversible or chronic kidney damage.

During normal kidney function, low molecular weight proteins, and only low levels of high molecular weight proteins, are filtered through the glomeruli and resorbed through the renal tubules. Thus, the presence of low molecular weight proteins in the urine is indicative of tubular dysfunction while high molecular weight urinary proteins may be indicative of glomerular dysfunction. Falck et al. (Ref. 40) observed both high and low molecular weight proteins in urine samples from seven cadmium-exposed workers and concluded that cadmium causes glomerular and tubular damage. Elinder et al. (Ref. 36) found that levels of low molecular weight proteins were substantially greater than levels of high molecular weight proteins. They argued that decreased tubular resorption, rather than increased glomerular permeability for larger proteins, was responsible for the changes.

Effects on the Endocrine System

Smirnov et al. (Ref. 141) examined urinary hormone levels in welders and persons in other occupational groups as a measure of strain and physical stress. Adrenalin and noradrenalin levels were signif-

icantly higher in electric arc welders working in poor conditions than in welders with generally satisfactory work conditions.

Effects on the Teeth and Oral Cavity

A survey of Swedish commercial divers indicated that thirty six of sixty six who performed underwater electric arc welding sensed a metallic taste in their mouth, possibly derived from degeneration of dental amalgams, when working with electrical equipment under water (Ref. 122). The appearance of dental amalgam restorations of twenty nine divers who performed underwater welding or cutting differed significantly from those of eleven divers who had not worked with underwater electrical equipment.

Effects of Hyperbaric Pressure

Bjorseth et al. (Refs. 20 and 21) discussed the need for research into the toxic effects of gases and fumes at hyperbaric pressures representative of the great oceanic depths experienced by underwater welders employed in off-shore oil operations. Preliminary work indicated that hyperbaric pressure can cause changes in the chemical composition and emission rates of welding fumes and gases. The toxic effects of chemicals may change under high hydrostatic pressure and chemical exposures may alter the physiological stress already inherent in deep sea diving.

Adverse physiological effects, including nervous excitation and changes in pulmonary function, can result from exposure to hyperbaric conditions in the absence of chemical exposures. That the stress already imposed upon the body by hyperbaric pressure can alter the effects of chemicals was suggested in studies of a few medications, anesthetics, and breathing gases which showed that effects seen at normobaric pressures cannot be extrapolated to hyperbaric conditions. New research into the effects of exposure to gases and fumes under hyperbaric conditions is necessary for the development of exposure guidelines appropriate for use in underwater welding.

Biological Monitoring

Investigations of urine or blood levels, or both, of nickel and chromium indicate that chromium, but not nickel, can be useful for monitoring worker

exposure (Refs. 2, 168, and 170). Akesson and Skerfving (Ref. 4) found no correlation between urinary nickel concentrations and the extent of nickel exposure.

Zober (Refs. 168 and 170) determined concentrations of nickel and chromium in the breathing zone and body fluids of twenty stainless steel welders. A linear relationship existed between exposure levels and post-shift concentrations in the urine and plasma for both hexavalent and total chromium. Preshift urinary chromium levels increased throughout the week indicating an accumulation of chromium in the body. It was concluded that workplace exposures to chromium can be successfully monitored by either urine or plasma analysis.

Koshi et al. (Refs. 75 and 76) measured the frequency of sister chromatid exchanges, chromosomal aberrations, and the number of chromosomes in lymphocytes from stainless steel welders. No significant difference was seen in the sister chromatid exchange frequency between welders and controls. Chromosomal aberrations, including chromosome gaps, aberrant metaphases, and chromatid and chromosome gaps, occurred slightly, but significantly more frequently in welders than in controls.

Sjogren et al. (Ref. 140) examined the relationship between urinary aluminum levels and exposure to fumes generated by GMAW of aluminum. Their study indicated that aluminum inhaled from welding fumes may be retained for long periods of time. Part of the inhaled aluminum is excreted rapidly in the urine following exposure while the remainder may be stored in the body and excreted slowly.

Diagnostic tests which measure the effects of lead on the heme system, such as measurement of zinc erythrocyte protoporphyrin (ZEP) and urinary coproporphyrin, are generally considered to be useful indicators of the biological effects of absorption of lead by the body, but are less useful than blood lead levels for monitoring acute lead exposures (Refs. 17 and 61).

Williams (Ref. 164) reported the case of a welder who had a massive acute exposure to lead while performing a temporary assignment in a lead-acid battery factory. The welder's blood lead levels were highly elevated; lead levels of 240 and 300 g/dl were measured on two separate occasions within two weeks after exposure. Urinary lead and coproporphyrin concentrations were only slightly elevated whereas ZEP rose for eight weeks and then slowly decreased.

That ZEP may be a better biological screening parameter than blood lead levels for chronic lead

exposure was reported by Kalnas and Alleyne (Ref. 70) who measured urinary aminolevulinic acid (ALAU), blood lead and ZEP in 142 lead-exposed workers. ZEP, but not blood lead levels, reflected symptoms of lead exposure in workers employed two years or less. ALAU levels tended to be indicative of longer term exposure.

Huel et al. (Ref. 62) examined whether cadmium and lead absorbed during occupational exposures are capable of reaching the human fetus by determining the concentrations of these metals in hair samples from newborns shortly after birth. The concentration of cadmium and lead in hair from exposed mothers and of cadmium in hair from their offspring were more than twice as high as concentrations in hair from unexposed controls. However, there was no correlation between maternal and newborn lead levels. This indicated that systemic cadmium, but not lead, exposure can be quantified by hair analysis of either the mother or the newborn.

Gorban et al. (Ref. 49) determined the manganese content in hair samples collected from 228 welders who performed CO₂-shielded GMAW. The investigators concluded that a direct relationship exists between the extent of manganese exposure and the concentration of manganese in hair.

Toxicologic Investigations in Animals and Cell Cultures

Animal Studies

Lam et al. (Ref. 79) found that exposure of guinea pigs for six days to 5 mg/m³ zinc oxide, a concentration equivalent to the threshold limit value (TLV - Ref. 1), caused alterations in pulmonary function. The lung weight was markedly increased and did not return to normal during the three-day post-exposure examination period. On the basis of this study, they suggested that the TLV may not be low enough to protect exposed workers.

That exposures to mixtures may be more harmful than individual components was demonstrated by Sylvestre and P'an (Ref. 150) who studied the effects of thirty-day exposures to ozone, carbon monoxide (CO), nitrogen dioxide (NO₂), and manganese dioxide (MnO₂) particles on the mouse lung. All experimental groups had emphysema and dilated alveoli. Emphysematic lesions were less extensive in animals that received a mixture of particulates and gases than

in those that received gases or particulates alone. However, the mixture of gases and particulates caused the most overall damage and produced numerous areas of inflammation, edema, and dilated blood vessels.

Pulmonary fibrosis was not observed in the lungs of rats treated by intratracheal instillation with fumes generated by CO₂-shielded GMAW (Ref. 50). LD₅₀'s, determined by intraperitoneal injection, indicated that the acute toxicity of particulates decreased as the welding current increased and that fumes from high alloy steel were substantially more toxic than those from low alloy steel.

To investigate the fibrogenic potency of welding fumes, Weller and Reichel (Ref. 163) injected welding fumes containing 88.5 percent iron, 7.5 percent manganese, 3.2 percent silicon, and 0.9 percent aluminum into the rat peritoneal cavity. After three months, a large number of macrophages and connective tissue fibers were associated with dust deposits. The fibrosis did not progress during the remaining nine months of the study. The investigators concluded that the discrete fibrotic changes in the peritoneum parallel changes seen in the human lung and that welding dusts cause a limited fibrotic response which does not progress into massive fibrosis. In a similar experiment, Malik et al. (Ref. 85) observed no signs of fibrosis in guinea pigs injected intraperitoneally with particulates generated by welding.

Olah et al. (Ref. 118) examined the lungs of Wistar rats twelve weeks after intravenous injection of welding fumes collected from SMAW and argon-shielded GTAW of austenitic steel. SMAW fumes produced a mild to moderate fibrogenic response in the lungs, but GTAW fumes were not fibrogenic.

Kalliomaki et al. (Ref. 69) compared the retention and clearance rates in rats exposed by inhalation to fumes from GMAW and SMAW of stainless steel. Chromium generated by GMAW was cleared from the lungs much more slowly than chromium from

SMAW. Nickel cleared rapidly at first and then, after several days, cleared much more slowly. A bimodal excretion pattern was noted for chromium. At first, chromium levels fell rapidly in the urine, with a half-life of eight hours. Two days after exposure ceased, urinary chromium excretion decreased to a half-life of thirty days.

In Vitro Studies

Bacterial Assays. Using a modified Salmonella/Ames assay, Biggart (Ref. 19) found that both the gas phase and particulates from mild steel welding fumes contained mutagens. These findings differ markedly from previous reports and warrant follow-up studies.

Mammalian Cell Studies. Hansen and Stern (Refs. 57 and 58) studied the cytotoxicity and transforming effects of welding fumes and their components on cultured baby hamster kidney cells (BHK-21) and Syrian hamster embryo (SHE) cells. Hexavalent chromium, but not trivalent chromium compounds, were cytotoxic and transforming (see *Mammalian Cell Studies*). The transforming potency and toxicity of fumes from SMAW of stainless steel were ten times greater than those from GMAW of stainless steel. Fumes from SMAW and GMAW of mild steel were only very weakly toxic and did not cause cell transformation.

Potebnia et al. (Ref. 127) tested the toxicity and cocarcinogenicity of three welding fume samples in SA7 adenovirus infected cultured rat kidney cells and hamster embryo cells. All fume samples enhanced the adenovirus-induced oncogenic transformation of both cell lines. When transformed cells were injected into animals, tumors developed more rapidly from cells treated with welding fumes and virus than from those treated with virus alone.