

Effects of Welding on Health, VII



American Welding Society



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Effects of Welding on Health — VII

Research performed by Biomedical Toxicology Associates, Rockville, Maryland, under contract with the American Welding Society and supported by industry contributions.

An updated (January 1986-December 1987) 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:

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July 1989

Abstract

This literature review, with 194 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 arc welding processes. 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. Referenced materials are available from Biomedical Toxicology Associates.

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Foreword

(This Foreword is not a part of *Effects of Welding on Health VII* , 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 consists of the reports *Effects of Welding on Health* (I through VI) 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 Biomedical Toxicology Associates.

Comparative Listing — Welding Processes

Explanatory Note: Terms used in the technical literature sometimes do not correspond to those recommended by AWS in its publication ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

Accordingly, the following list may aid the reader in identifying the process in use.

<u>EWB — VII</u>		<u>Preferred AWS Term</u>
Gas or Flame Cutting	(OC)	Oxygen Cutting or (OFC) Oxyfuel Gas Cutting
Gas Welding	(OFW)	Oxyfuel Gas Welding or (OAW) Oxyacetylene Welding
MAG	(GMAW)	— (with specified shielding gas)
MIG, GMA	(GMAW)	Gas Metal Arc Welding
MMA, SMA	(SMAW)	Shielded Metal Arc Welding
TIG	(GTAW)	Gas Tungsten Arc Welding
Wire		Electrode

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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*. Six volumes have been published to date; the first covered data published before 1978, while the latter five covered time periods between 1978 and December 1985. The current report includes information published between January 1986 and December 1987. 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 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 many 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 the risk of cancer from these exposures has not been clearly 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

The Respiratory Tract

Much of the recent research performed on the health effects of welding involved the respiratory tract. Of major concern was whether exposure to welding emissions induces conditions such as reduction in pulmonary function, bronchitis, and emphysema. Essential to this question is whether pulmonary impairments are associated with exposure to specific component(s) of welding emissions and the identification of welding electrodes that produce less hazardous emissions.

Rounded opacities or shadows are frequently observed in chest X-rays of welders. These opacities represent deposits of fume particles in the respiratory tract and are not usually associated with loss of pulmonary function. Larger and coalescent shadows reflect fibrotic processes and do not usually result from welding exposures. X-ray shadows often regress after welding exposure ceases. A recent study by Desmeules and Tardif indicated that the continued progression of X-ray opacities after welding exposures ceased is associated with exposure to lung irritants from sources other than welding (Ref. 33).

Some investigators have reported that a mild reduction in pulmonary function accompanies the appearance of nodular shadows in X-rays. However, there are reports to the contrary and other investigators consider pneumoconiosis in welders to be a benign condition. The literature shows many disparities among the results of lung function tests in welders. During this report period, deficits in pulmonary function among welders were reported in two studies, while two others found no correlation between welding exposures and abnormalities in pulmonary function. These disparities may result from the use of tests that measure the function of those parts of the respiratory tract least likely to be affected by welding fumes. Other disparities arise from studies of heterogeneous populations. The

quantities and chemical characteristics of gaseous and particulate components of welding emissions vary widely with the welding method. Since the effects on the respiratory tract can be expected to vary as well, it is important to correlate observed effects on the respiratory tract with the welding method used.

Cancer

Thirteen new cancer epidemiology studies were conducted which included welders among the study populations. In most of these, the inclusion of welders was incidental and little information could be obtained about the duration of exposure, type of welding process used, or possible important nonwelding exposures. Only one study specifically examined a cohort of welders; no excess cancer of any type was found among the 3000 welders examined (Ref. 25). Of the eight studies which evaluated lung cancer rates, four found a significant association between welding and lung cancer. In three of these, exposures to carcinogens from nonwelding processes could not be ruled out (Refs. 90, 152, 158, 161, and 162).

An elevated risk for leukemia was noted in a shipyard study performed by F. B. Stern (Ref. 169). In contrast, R. M. Stern found no association between welding exposures and leukemia in his analysis of 15 epidemiologic studies which considered the incidence of leukemia in welders (Ref. 170). Similarly, an elevated risk for brain tumors was found by McLaughlin in a population-based study in Sweden (Ref. 97), but no brain tumors were identified in a death-certificate study by Thomas in the U.S. (Ref. 175), or in a case-control study conducted by Olin in Sweden (Ref. 123). Isolated studies reported elevated risks for cancer of the kidney (Refs. 158 and 161), gastrointestinal tract (Ref. 141), nasal sinus (Ref. 52), and pancreas (Ref. 109).



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A major argument supporting the probability of an increased cancer risk in some welders is the presence of nickel and hexavalent chromium in fumes from some welding processes. The mechanism of action of metal carcinogens remains unknown and is an important area for further research. Epidemiologic studies differ widely in their conclusions concerning the cancer risk of welders. Most of the 13 cancer epidemiology studies reviewed in this volume of *Effects of Welding on Health* were of general populations, making it difficult to rule out non-welding exposures. More carefully controlled studies of welding populations are critically needed to help understand the risk of cancer in welders. Studies of large populations of welders, in which exposures to specific welding processes can be carefully delineated are necessary to provide a much needed answer to the question of whether exposures to specific fumes account for the elevated cancer risk observed among some welding populations.

Effects on the Urogenital Tract

With the exception of cadmium-induced kidney damage, kidney disease is not generally associated with welding. This was confirmed by two epidemiologic studies which found no relationship between welding and the incidence of chronic kidney disease (Refs. 51 and 193). However, chronic exposure to low concentrations of cadmium fumes can cause kidney damage, which is first manifested by urinary excretion of low molecular weight serum proteins. Signs of kidney tubular dysfunction were found among workers exposed to cadmium in welding and soldering fumes and aerosols from cadmium-containing paints (Refs. 164 and 184). A study of solderers with a work history of high cadmium exposures and signs of kidney tubular dysfunction suggested that mild tubular proteinuria will not progress to more severe kidney dysfunction in the absence of further exposure to cadmium (Ref. 164).

Biological Monitoring

Because hexavalent chromium passes more readily through cell membranes, trivalent chromium tends to be transported by plasma while hexavalent chromium is transported mainly in erythrocytes (Ref. 3). Based on the possibility that this difference could be used to distinguish between exposures to trivalent and hexavalent chromium,

two research groups examined chromium levels in plasma and red blood cells of stainless steel welders. Angerer et al. (Ref. 4) concluded that simultaneous determination of chromium levels in plasma and erythrocytes may give a useful picture of overall exposure to both total chromium and hexavalent chromium. In contrast, Gustavsson and Welinder (Ref. 50) concluded that determination of blood or erythrocyte chromium levels would not add important information to that gained from biological monitoring of urinary chromium concentrations. Further studies are needed to establish the utility of chromium distribution between plasma and red blood cells in biological monitoring.

Stability of Welding Fumes

Recent work revealed that particles in some welding fumes undergo chemical and morphological changes in the lung. Physicochemical studies by Stern et al. (Ref. 172) indicated that substituted magnetite is the primary magnetic component in freshly formed shielded metal arc welding (SMAW) fumes whereas a less substituted form of magnetite appeared to be the predominant magnetic component of fumes that have been retained in the lungs. Similar findings were reported by Kalliomaki et al. (Ref. 76). They conducted an *in vivo* rat study which showed that the remanent magnetic fields of fumes generated by SMAW of stainless steel and gas metal arc welding (GMAW) of mild steel are not stable in the lungs.

Other *in vivo* studies showed that there is a marked difference in pulmonary clearance rates of fumes from SMAW and GMAW of stainless steel (Refs. 70, 71, and 73). Anttila demonstrated that these differences are related to differences in the solubility of particles in the lung (Refs. 6 and 7). The morphology and chemical composition of particles were examined periodically in rat lungs after exposure to welding fumes by inhalation. The majority of particles in SMAW fumes had irregular shapes and were enriched with sodium and potassium. These particles changed with time, losing practically all sodium, potassium, and chromium, and also some manganese. Eventually, so much material was lost that the particles became transparent. In contrast, the particles from GMAW fumes showed no signs of dissolution. Thus, the solubility of particle populations may be an important determinant in the pulmonary clearance of welding fumes.

Technical Summary

The Exposure

Fumes

A major objective of research performed on the composition of emissions from different electrodes and welding processes is to identify those methods which generate the least harmful pollutants. Such information is also useful for selection of electrodes for use in the workplace. Many studies of the composition of fumes, and the rate of fume emission from different welding processes, were published in 1986 and 1987.

An industrial hygiene survey conducted in six Dutch factories showed that the fume and gas exposures from plasma welding of stainless steel were comparable to the low exposures produced by gas tungsten arc welding (GTAW). Exposures from plasma cutting of stainless steel were comparable to those produced by SMAW (Ref. 183). Henderson et al. showed that the fume generation rate (FGR) was lower for gas shielded flux cored electrodes than for those used without gas shields (Ref. 58). With resistance welding, the quantity of emissions increased markedly during "splashing" and also when welding greased surfaces (Ref. 85). Studies of the effects of hyperbaric pressure on fume emission demonstrated that the ratio of manganese to iron increases, and the FGR is 5 to 10 times greater when performing GTAW at a pressure of 32 bar than at 1 bar (Ref. 16).

McIlwain and Neumeier determined FGRs and fume constituents generated by selected coated electrodes commonly used in mines (Ref. 96). Olah and coworkers quantified gases (ozone, hydrogen fluoride, and nitrogen oxides) and light and heavy elements [Fe, Cr, Cr(VI), Ni, Mn, Mo, Si, C, and others] in fumes produced by coated electrodes, flux cored hardfacing electrodes (Refs. 115, 116,

118, and 119), and by electrodes used for welding of high alloy steels (Refs. 117 and 177). They found that exposures resulting from hardfacing are comparable to those from SMAW of high alloy steels (Ref. 116). Tandon et al. determined 19 elements in the flux and fume from three types of hardfacing and two types of high strength, low alloy steel coated electrodes. An inverse relationship between the fluoride concentration in the fume and the FGR was found. There was a positive relationship between sodium and potassium concentrations in the flux and the ratio of water-soluble hexavalent chromium to total chromium in the fume (Ref. 174).

The concentration of hexavalent chromium in GMAW fumes is substantially greater in fume samples collected by wet impingement than in those collected by traditional filtration methods (Ref. 137). A study by Hewitt and Madden of GMAW fumes collected by wet impingement suggested that reactions between trivalent chromium oxides and ozone may be responsible for the formation of hexavalent chromium (Ref. 59). Wiseman and Chapman (Ref. 190) found traces (0.1 ppb) of nickel carbonyl in fumes produced by GTAW of nickel alloys with shield gases containing carbon monoxide or carbon dioxide (CO₂).

Several research groups described methods for determination of chromium and other elements in welding fumes by X-ray fluorescence analysis (Ref. 106, 120, and 186). Sawatari and Serita (Ref. 148) designed a method using a series of leaching solutions to differentiate between chromium of different valences and solubilities. Methods employing high pressure liquid chromatography (Ref. 94) and atomic absorption spectrometry (Ref. 21) to analyze elements in welding fumes were described by other investigators. Three research groups published methods for measuring trace quantities of metals in biopsied lung tissue (Refs. 7, 10, 88, and 89).

Particles

Welding fumes are composed of microscopic particles which tend to be of respirable size. The outer surface of particles from SMAW fumes are composed primarily of lighter elements derived from the flux (e.g., Na, K, Ca, F), while heavier elements derived from the filler metal (e.g., Fe, Cr, Ni, and Mn) tend to predominate in the particle core (Refs. 48 and 187). Kalliomaki et al. (Refs. 47, 49, and 72) classified particles in fumes from SMAW, GMAW, and flux cored arc welding (FCAW) of mild steel into four groups on the basis of their morphology: clusters of globules, chains, granular networks, and large spheres. The distribution of the particle classes varied with the welding process.

Ahlberg et al. determined the mass median aerodynamic diameter (MMAD), the equivalent mobility diameter (DME), and the growth in particle size as a function of relative humidity for particles in fumes from SMAW of mild steel (Ref. 2). They concluded that hydrated particles could collapse to spheres after entering the respiratory tract which would cause the MMAD to increase and the DME to decrease. This would result in increased sedimentation and diffusion rates, and would thereby cause greater particle deposition in the alveoli.

Gases

Engstrom and Virtamo determined ozone levels in the breathing zone of welders from 24 welding shops using different gas shielded welding processes (Ref. 39). The mean concentrations for all welding processes was less than the Finnish standard of 0.1 ppm. GMAW of aluminum produced the highest ozone concentrations with a geometric mean of 0.06 ppm. The addition of nitric oxide to the shield gas was less effective in reducing ozone levels than predicted by the laboratory studies of Sipek and Smars (Refs. 132 and 157).

Electromagnetic Radiation

Okuno estimated permissible exposure times at 1 meter from the source for the ultraviolet (UV) and blue light generated by various welding processes (Refs. 113 and 114). The permissible exposure times for UV light varied from several seconds to one minute for most of the welding processes studied. For each welding process, the intensity of the UV, but not the blue-light radiation, increased with

the diameter of the wire, arc current, and voltage. As expected, the UV hazard was greater with GMAW than with SMAW. The greatest blue-light hazard was found for CO₂-shielded GMAW of mild steel, for which a permissible daily exposure time of 42 seconds was estimated. In similar work, Salsi and Barlier measured the spectral emissions from UV to far infrared light generated by 47 diverse coated electrodes (Ref. 9).

Production Coatings

Heikila et al. found that concentrations of benzo(a)pyrene as high as 0.64 micrograms/m³ were present in the vicinity of welders during SMAW of railroad ties (Ref. 53).

Noise

Impulse noise may be more harmful to hearing than continuous steady state noise of the same energy level (Ref. 133). The impulse noise level has been defined as the difference between the peak value and the root mean square of the slow time-weighted value. Noise is considered to be impulsive if the difference between peak levels and the slow time-weighted value is greater than 15 dB. A study conducted in a shipyard assembly hall indicated that the impulsiveness for different processes increases in the following order: gouging < carbon arc gouging < chiseling < welding (process not specified) < GMAW (Ref. 168). Further tests indicated that earmuffs effectively attenuate impulsiveness (Ref. 138).

Hygiene and Work Practices

Accidents, the primary health risk associated with the use of robots, occur most often during teaching, testing, and maintenance. Accidents may result from pushing the wrong button in the robot controls, by improper programming of robot movement, or by difficulties in perceiving or anticipating the movement of the robot arm during work operations (Refs. 56, 57, and 134).

A fatal accident occurred in which a welder was working inside a vapor degreaser pit filled with 1,1,1-trichloroethane vapors. While welding, the vapors ignited and the welder fell into the pit, where he died. Tests of the 1,1,1-trichloroethane remaining after the accident indicated that it contained twice the quantity of corrosion inhibitors normally

present, which may have contributed to the flammability of the vapors (Ref. 30).

Protective Gear. A study by Sliney et al. (Refs. 12 and 163) indicated that most fabrics used in standard work clothing provide adequate attenuation of the UV radiation generated by welding. Laundering decreased the UV transmission through most fabrics tested. This was thought to be due to shrinkage of the fabric, with a consequent decrease in the size of the openings between fibers.

A study by Beckett et al. (Ref. 11) demonstrated that wearing vapor-barrier garments in the workplace can cause heat stress. The authors noted that when heavy muscular work is performed in a warm environment, impairment of the dissipation of sweat by vapor-barrier garments can result in significantly higher body temperatures with a high risk for heat-related disorders, including heat stroke.

Jakubcik (Ref. 66) described a lightweight, maintenance-free, disposable respirator used in a steel works in Czechoslovakia to provide protection when welding high alloy steels with electrodes containing chromium, nickel, and manganese. Several methods for extracting welding fumes from the work area (Refs 67 and 145) and from hyperbaric chambers (Ref. 35) were published.

Training. Rosen and Lundstrom coupled video taping of workers and direct reading instrumentation of breathing zone exposures (Ref. 146). The resultant video tape of work practices with a superimposed presentation of real-time exposure data was used to evaluate the relationship between exposures to fumes, dusts or solvents with individual work patterns, and to train persons who work with hazardous substances.

Effects of Welding on Human Health

Respiratory Tract

Alveolar Macrophages. Pierre et al. (Ref. 140) examined the interactions of welding fumes with two lung antiproteases. They found that fume particles bind reversibly to the antiproteases and prevent them from inhibiting the activity of proteolytic enzymes.

Mylius and Gullvag showed that sputum from coke plant workers, aluminum plant potroom workers, asphalt workers, and shipyard welders contain

more alveolar macrophages than controls. Combined smoking and occupational exposures produced a marked increase in the number of macrophages (Ref. 104).

Estimation of Retained Particles in the Lungs. Magnetopneumography utilizes the magnetic properties of inhaled particles to estimate the burden of occupational dusts in the respiratory tract. Kalliomaki et al. developed a magnetopneumograph that measures pulsed coercive force which can discriminate between remanent fields produced by different types of fumes (Ref. 75). An innovation introduced by Drenck and Stern (Ref. 36) used an AC susceptibility bridge to provide information about the total content of ferromagnetic, paramagnetic, and diamagnetic material. Using this system, Stern et al. (Ref. 172) obtained evidence for in vivo changes of welding fume particles from the substituted magnetite present in freshly formed welding fumes to unsubstituted magnetite. These findings were supported by studies with X-ray diffraction and Mossbauer spectroscopy which indicated that substituted magnetite is the primary magnetic component in freshly formed welding fumes, whereas a less substituted form of magnetite is the predominant magnetic component in inorganic dust obtained from ashed lungs of deceased welders.

A study in which fumes were administered to rats by intratracheal instillation also indicated that the magnetic properties of some welding particles are not stable in the lungs (Ref. 76). The specific magnetic moment of welding fumes generated by SMAW of mild steel and GMAW of stainless steel were stable, while the magnetic moment of welding fumes generated by SMAW of stainless steel and GMAW of mild steel decreased by about 50% during the 106-day period following the introduction of fumes into the lungs.

Pulmonary Function and Bronchitis. Chest X-ray abnormalities, and deficits in lung function, excess chronic bronchitis, or both, among welders were examined in 13 studies. Of these, two were confounded by exposure to asbestos or other nonwelding exposures in the workplace (Refs. 34 and 122).

Nodular opacities are frequently observed in chest X-rays of welders. These opacities are not usually associated with loss of lung function or diseases of the respiratory tract. During the current report period, two studies indicated that siderosis or pneumoconiosis in welders is not associated with a reduction of lung function (Refs. 26 and 166) while two other studies (Refs. 84, 150, and 151) concluded that such an association exists. Chest X-ray

shadows often regress after welders retire or are removed from further exposure. Desmeules et al. found that workplace exposures other than welding existed in cases where opacities increased or progressed after welding exposures ceased (Ref. 33).

While bronchitis and loss of pulmonary function were attributed to welding exposures by several investigators, the reports differed in their conclusions concerning the contribution of tobacco smoke to the development of respiratory impairments. Five studies found that nonsmoking welders have an excess risk of bronchitis (Refs. 81, 82, 84, 92, 102, and 149) while two found an elevated incidence of bronchitis only among welders who smoked (Refs. 26 and 166).

Similar disparities exist among reports of the influence of tobacco smoke on the induction of impairments in lung function. Two studies found deficits in pulmonary function only in smoking welders (Refs. 26 and 166) while three other studies found an elevated incidence of pulmonary deficits in both smoking and nonsmoking welders. In a small cohort of shipyard welders, Kalliomaki found deficits in pulmonary function only among retired shipyard welders and not among the younger, active welders (Ref. 74).

Although there are conflicts among these reports, the results suggest that nonsmoking welders may develop bronchitis and deficits in pulmonary function. Welders who smoke clearly have an elevated risk for both bronchitis and pulmonary deficits. Whether the combined effects of smoking and welding exposures are additive or synergistic is not established. The study of shipyard welders by Lyngenbo et al. (Ref. 92) carefully controlled for exposure to cigarette smoke, asbestos and exposure to other lung toxicants. This study demonstrated that welding alone can cause bronchitis, upper respiratory tract symptoms, and reduced lung function. The effects of cigarette smoke on the development of these symptoms were additive.

The influence of constituents of welding fumes on the development of pulmonary impairments was examined by two research groups. Krasnyuk et al. found that welders of high alloy steel were more likely to have extensive pneumoconiosis with more severe restrictive disturbances in pulmonary function than welders of low alloy steel (Ref. 84). Ulrich et al. found no differences in pulmonary function between welders with high and low chromium exposures (Ref. 179).

Acute Respiratory Tract Disease — Case Report.

The case of a welder who developed a sudden, work-related onset of pulmonary disease was described

by Silberschmid (Ref. 156). Examination revealed swollen and red bronchial mucosa, irregular opacities in chest X-rays, and deficits in pulmonary function. Extreme inflammatory changes were found in biopsied lung tissue. Symptoms of exertional dyspnea, bronchial hyperreactivity, and recurrent pneumonias persisted for 7 years. Prior to the onset of disease, he had been working without properly functioning local ventilation and was exposed to high concentrations of fume.

Production Coatings. Emmerling et al. (Ref. 38) found no significant abnormalities in pulmonary function among 35 workers who welded metals primed with zinc chromate, polyvinylbutyral coatings or alkyl paints. In addition, there was no correlation between work place exposure and concentrations of zinc, hippuric acid, methylhippuric acid, formic acid, or carboxyhemoglobin in blood or urine samples. The number of participants in the study was small, and measurements of airborne chemicals indicated that exposures were low.

Cancer

Thirteen new cancer epidemiology studies were conducted which included welders among the study populations. Eight of these were case-control studies, while the remainder were population-based morbidity and mortality studies. Only one study specifically examined a cohort of welders. In that study, no excess cancer of any type was found among the cohort of 3000 welders (Ref. 25). Of the eight studies which evaluated lung cancer rates, four found a significant association between welding and lung cancer. In one of these, there was also a high incidence of mesothelioma and, thus, asbestos exposure could not be ruled out (Refs. 158, 161, and 162). A second study found an excess of lung cancer among shipyard welders, but not among welders who did not work in shipyards (Ref. 152), which suggests the effects of exposures other than welding. The remaining two were case-control studies in which the total number of welders with lung cancer were 28 (Ref. 83) and 19 (Ref. 90). In the latter, Lerchen cautioned that "the welders in our study had worked in diverse industries that may have involved exposures other than welding that also increased the lung cancer risk" (Ref. 90). Because of the possibilities of confounding exposures, it is difficult to draw firm conclusions concerning the lung cancer risk of welders on the basis of studies described above.

Other tumors reported to be associated with

welding include leukemia, cancer of the stomach, brain, nasal sinus, and pancreas. An elevated risk for leukemia was noted in a shipyard study performed by F. B. Stern (Ref. 169). In contrast, R. M. Stern found no association between welding exposures and leukemia in his analysis of 15 epidemiologic studies which considered the incidence of leukemia among welders (Ref. 170). Similarly, an elevated risk for brain tumors was found by McLaughlin in a population-based study in Sweden (Ref. 97), but no brain tumors were identified in a death-certificate study by Thomas in the U. S. (Ref. 175), or in a case-control study conducted by Olin in Sweden (Ref. 123). One study found an elevated risk for renal tumors in welders (Ref. 161), while isolated studies also reported elevated risks for cancer of the gastrointestinal tract (Ref. 141), nasal sinus, (Ref. 52) and kidney (Ref. 158). Norrell conducted a case control and morbidity and mortality study of pancreatic cancer (Ref. 109). An elevated incidence of pancreatic cancer in welders was observed in the case-control but not in the mortality study.

Screening for Cancer. A nontraumatic method for screening workers at risk of nasal cancer was reported by Reith et al. This cytologic screening method examines a representative population of cells obtained by brushing the surface of the middle nasal turbinate. In a study of nickel refinery workers with known nasal dysplasia, more cases of pre-neoplastic nasal lesions were detected by cytologic screening than by biopsy (Ref. 144).

Metal Fume Fever

Vogelmeier et al. (Ref. 185) observed changes in pulmonary function and marked pulmonary inflammation in a welder who had recurring symptoms of metal fume fever after welding zinc-coated materials, but not other metals. Abnormalities in pulmonary function and a marked increase in polymorphonuclear leukocytes in bronchoalveolar lavage fluid were associated with symptoms of metal fume fever.

A case of metal fume fever with a severe, concomitant allergic reaction to zinc fumes was reported by Farrell (Ref. 40). After welding galvanized metal, the patient experienced classic symptoms of metal fume fever associated with an immediate anaphylactoid reaction to zinc fumes as well as a delayed reaction consisting of angioedema and urticaria.

Effects on the Eye and Vision

Keratoconjunctivitis, a painful inflammation of the cornea, is the eye condition most frequently encountered by welders. Although this condition usually lasts for up to 2 days, Sharir and Ben-David observed severe symptoms of keratoconjunctivitis which persisted for several months in four workers employed in plasma arc thermal spray coating (Ref. 153).

Two cases of photic maculopathy, in which visual loss was noted soon after exposure to the welding arc, were reported (Refs. 20 and 180). In one of the cases, some visual loss and signs of retinal injury were present 6 months after the incident (Ref. 180).

An unusual case of retinal damage in a man with a lens implant was reported by Turut et al. (Ref. 178). Four years after the surgery, he welded without wearing eye protection and experienced an immediate loss of visual acuity. A small lesion, apparently caused by radiation from the arc, was present on the retinal fovea of the eye with the lens implant. There were no indications of damage or loss of vision in the eye with the normal lens.

Effects on the Skin

A case of a welder with recurrent, severe facial dermatitis was described by Shehade et al. (Ref. 154). Allergic dermatitis was ruled out by skin patch testing with a battery of allergens. The welder had routinely performed spot welding without a protective face mask. His case was diagnosed as photodermatitis, caused by UV exposure during welding.

Sensitivity to Fume Components

A case of a welder who had anaphylactoid reactions following exposure to chromates was reported by Moller et al. (Ref. 101). The symptoms included urticaria, difficulty breathing and chest tightness. Nordman et al. examined 58 stainless steel welders who had asthmatic reactions when welding stainless steel. Some of these welders responded positively to the histamine provocation test prior to welding and had significant reductions in pulmonary function following welding of stainless steel (Ref. 108).

Effects on the Musculoskeletal System

Two techniques for analyzing causes of postural stress were described. One was a computer-aided system used to analyze working postures of the trunk and shoulders on repetitive assembly line jobs (Ref. 78). Both systems were applied to improving postural stress incurred during welding operations (Refs. 55 and 78).

Effects on the Urogenital Tract

Chronic exposure to low concentrations of cadmium fumes can cause kidney damage, which is first manifested by urinary excretion of low molecular weight serum proteins such as beta-2-microglobulin and retinol-binding protein. Signs of tubular dysfunction, but not glomerular dysfunction, were found among a group of 26 cadmium-exposed workers by Verschoor et al. (Ref. 184). Smith et al. found low molecular weight proteins (typical of tubular dysfunction), but not albumin (characteristic of glomerular dysfunction) in the urine from 20 of 51 solderers with up to 25 years of uncontrolled exposure to fumes from cadmium-containing alloys. No significant changes in beta-2-microglobulin were found in 19 solderers followed for 2 years after cadmium exposure ceased, suggesting that mild tubular proteinuria will not progress to more severe kidney dysfunction in the absence of further exposure to cadmium (Ref. 164).

Two epidemiologic studies showed no association between renal impairment and welding. In the first, elevated levels of nickel and chromium were found in the urine of stainless steel welders, but kidney function, assessed by measurement of total protein and enzyme activity in urine, was comparable to that of the control group (Ref. 193). The second study examined kidney function in 143 males who had received kidney biopsies as a result of suspected or clinically established glomerulonephritis or obscure renal disease. There was no relationship between welding and the incidence of severe chronic kidney disease nor was there an increase in the risk of death from nephritis among welders (Ref. 51).

Effects on the Teeth

To investigate the cause of a metallic taste sensation and loosening dental amalgams among underwater welders, Ortendal et al. investigated the

intraoral electrical and magnetic activity during underwater welding. Humidity was the predominant factor in the generation of intraoral electrical activity. However, even when water was deliberately introduced into the diver's suit, the intra-oral electric field was too small to damage dental amalgam. No correlation was found between the magnetic field and a metallic taste in the mouth. In vitro studies indicated that a slight degeneration of dental amalgams may be caused by magnetic fields equivalent to those generated by welding. However, chemical changes were insufficient to account for a metallic taste sensation.

Biological Monitoring

Sjogren et al. (Refs. 159 and 160) examined the relationship between urinary aluminum concentrations and exposure to fumes generated by GMAW and GTAW of aluminum. Urinary aluminum levels were dependent on the most recent daily exposures as well as on the total duration of exposure. The results indicated that aluminum is probably stored in two or more compartments in the body, with widely different clearance rates.

Two studies were based on findings that red blood cells are permeable to hexavalent, but not trivalent, chromium (Refs. 4 and 50). Angerer et al. (Ref. 4) determined chromium concentrations in the breathing zone and in erythrocytes, plasma and urine from 103 male welders who performed SMAW or GMAW, or both, of stainless steel. Chromium levels in erythrocytes were too low to provide accurate estimates of exposure below airborne concentrations of 100 micrograms/m³. However, the investigators concluded that simultaneous determination of chromium levels in plasma and erythrocytes may give a useful picture of exposure to total and hexavalent chromium.

Different conclusions were drawn by Gustavsson and Welinder (Ref. 50) who observed no obvious differences in clearance rates of erythrocyte and plasma chromium in studies performed with four stainless steel SMA welders and six electroplaters. These investigators concluded that determination of blood or erythrocyte chromium levels would not add important information to that gained from biological monitoring with urinary chromium concentrations.

Zschiesche et al. (Ref. 194) determined levels of manganese in the breathing zone and body fluids of eight welders from two factories who worked with filler materials containing about 0.8% manganese. Levels of manganese in blood and urine tended to