

Effects of Welding on Health, IX



American Welding Society



Documents

Document Sharing Hub

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

Effects of Welding on Health IX

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

Performed by:

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

Abstract

This literature review, with 232 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 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.

Prepared for
Safety and Health Committee
American Welding Society
550 N.W. LeJeune Road
Miami, Florida 33126

International Standard Book Number: 0-87171-462-0

American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126

© 1995 by American Welding Society. All rights reserved.
Printed in the United States of America.

This report is published as a service and convenience to the welding industry and is the product of an independent contractor (Biomedical Toxicology Associates) which is solely responsible for its contents. The materials in this report have not been independently reviewed or verified and are offered only as information. AWS assumes no responsibility for any claims that may arise from the use of this information. Users should make independent investigations to determine the applicability of this information for their purposes.

Personnel

<i>K. A. Lyttle, Chairman</i>	Praxair, Incorporated-Linde Division
<i>J. F. Hinrichs, 1st Vice Chairman</i>	A. O. Smith Corporate Technology
<i>M. T. Neu, MD, 2nd Vice Chairman</i>	Caterpillar, Incorporated
<i>M. E. Kennebeck, Jr., Secretary</i>	American Welding Society
<i>J. T. Ashe</i>	Snyder General Corporation
<i>W. J. Astleford*</i>	Southwest Research Institute
<i>K. L. Brown</i>	The Lincoln Electric Company
<i>O. J. Fisher*</i>	Consultant
<i>S. S. Glickstein*</i>	Westinghouse Electric Corporation
<i>W. S. Howes</i>	National Electrical Manufacturers Association
<i>A. F. Manz</i>	A. F. Manz Associates
<i>R. J. Simonton*</i>	Consultant
<i>D. H. Sliney*</i>	U. S. Army Environmental Hygiene
<i>W. O. Thompson*</i>	U.S. EPA
<i>R. J. Tucker*</i>	Glendale Protective Tech
<i>R. M. Tuggle*</i>	U.S. Department of Energy
<i>M. J. Vasquez*</i>	Shell Oil Company

*Advisor

Foreword

(This Foreword is not a part of *Effects of Welding on Health IX*, 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 I through VIII 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
P.O. Box 3539
Frederick, MD 21701
Tel. (301) 662-0783

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.

EWI — IX		Preferred AWS Term
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

Acknowledgments

Funds for this project were provided by the American Welding Society.

The American Welding Society gratefully acknowledges the financial support of the program by industry contributions.

Supporting Organizations

Air Products and Chemicals, Incorporated
Airco Welding Products
Allis-Chalmers
Alloy Rods Division, The Chemetron Corporation
AWS Detroit Section
AWS New Orleans Section
Arcos Corporation
The Binkley Company
Caterpillar Tractor Company
Chicago Bridge and Iron Company
Grove Manufacturing Company, Division of Kidde, Incorporated
General Electric Company
The Heil Company
Hobart Brothers Company
INCO Alloys International
Lincoln Electric Company
Miller Electric manufacturing Company
National-Standard Company
A.O. Smith Corporation
Teledyne-McKay, Incorporated
Trinity Industries, Incorporated
Truck Trailer Manufacturers Association
Walker Stainless Equipment Company
Weld Tooling Corporation

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

Table of Contents

	Page No.
<i>Personnel</i>	iii
<i>Foreword</i>	iv
<i>Comparative Listing — Welding Processes</i>	v
<i>Acknowledgments</i>	vi
<i>Introduction</i>	1
<i>Executive Summary</i>	3
<i>Technical Summary</i>	7
<i>Conclusions</i>	17

Section One — The Exposure

1. <i>Introduction</i>	19
2. <i>Fumes</i>	19
2.1 Analytical Techniques	22
2.2 Analysis of Metals in Biological Tissues	22
3. <i>Workplace Exposure Limits</i>	22
4. <i>Ozone</i>	23
5. <i>Electromagnetic Radiation</i>	25
6. <i>Electromagnetic Fields</i>	26
7. <i>Incidental Exposures</i>	26
7.1 Production Coatings	26
7.2 Radiation Exposure	26
8. <i>Hygiene and Work Practices</i>	27
8.1 Ventilation and Air Cleaning Equipment	27
8.2 Protective Gear	27
8.3 Accidents	28
8.4 Stress	29

Section Two — Effects of Welding on Human Health

9. <i>Respiratory Tract</i>	29
9.1 Pulmonary Function and Bronchitis	29
9.2 Case Reports	32
10. <i>Cancer</i>	33
10.1 Lung Cancer	33
10.2 Nasal and Laryngeal Cancer	37
10.3 Urogenital Tract Cancer	37
10.4 Cancer in Children of Welders	37
10.5 Cancers Associated with Electromagnetic Fields	38
10.6 Cancers Associated with Ultraviolet Radiation	38
11. <i>Metal Fume Fever</i>	39
12. <i>Effects on the Ear</i>	39
13. <i>Effects on the Eye and Vision</i>	40

13.1 Cataracts	40
13.2 Photokeratitis	40
13.3 Eye Injury	41
13.4 Long-Term Effects	41
13.5 Contact Lenses	41
14. <i>Effects on the Skin</i>	42
15. <i>Effects on the Nervous System</i>	42
16. <i>Effects on the Immune System</i>	43
17. <i>Effects on the Musculoskeletal System</i>	43
18. <i>Effects on the Kidney</i>	46
18.1 Cadmium	46
18.2 Chromium	46
19. <i>Fertility</i>	46
20. <i>Teeth</i>	49
21. <i>Effects of Specific Metals</i>	49
21.1 Beryllium	49
21.2 Cadmium	50
21.3 Iron	50
22. <i>Biological Monitoring</i>	50
22.1 Chromium: Biomarkers	50
22.2 Chromium: Biological Monitoring	51
22.3 Nickel	52
22.4 Aluminum	52
22.5 Zinc	53
23. <i>Incidental Exposures</i>	53
23.1 Degreasing Agents	53
23.2 Coated or Contaminated Surfaces	53
23.3 Allergens	54

Section Three — Effects in Animals and Cell Cultures

25. <i>Fertility</i>	54
26. <i>Fibrosis</i>	55
27. <i>In Vitro Tests</i>	55
28. <i>Effects of Welding Fumes in Animals</i>	56
29. <i>Biochemical Studies</i>	56
References	59

List of Tables

Table	Page No.
1. Lung Cancer in Welders, Cohort Studies	34
2. Lung Cancer in Welders, Case-Control Studies	35
3. Effect of Short-Term Exposure to Tri- and Hexavalent Chromium on Testicular Weight, and Number of Spermatozoa per Epididymis in Adult Wistar Rats	55
4. Metal Content of Fumes from Electrodes Tested in Lipid Peroxidation Assays	57

List of Figures

Figure	Page No.
1A. Fume Generation Rate During GMAW of Mild Steel Using Solid Mild Steel Wire Showing the Effects of Increasing Concentration of CO ₂ in the Shield Gas with Increasing Current	21
1B. Fume Generation Rate During GMAW of Stainless Steel Using Solid Stainless Steel Wire Showing the Effects of Helium in the Shield Gas with Increasing Current	21
1C. FGR for GMAW of Aluminum Alloys Containing Either 5% Magnesium (Alloy No. 5636) or 5% Silicon (Alloy No. 4043) Showing Effect of Magnesium in the Metal and Helium in the Shield Gas with Increasing Current	21
2. Cumulative Frequency Distribution of Welding Fume Concentrations in the Breathing Zone of Welders During Welding without the Use of Local Exhaust Ventilation	24
3. Frequency of Physical Symptoms Affecting Different Parts of the Musculoskeletal System	44
4. Drawing of Hand Showing Location of Carpal Tunnel and Position of the Median Nerve Affected by Carpal Tunnel Syndrome	45
5A. Cadmium Levels in Serum from Six Welders During the First 5 Years After Exposure to Cadmium Ceased	47
5B. Cadmium Levels in Urine in Six Welders During the First 5 Years After Exposure to Cadmium Ceased	47
5C. Concentrations of Beta 2-Microglobulin in Urine of Six Welders During the First 5 Years After Exposure to Cadmium Ceased	48
6. Aluminum Concentrations in Urine from Two Welders During the First 4 Years After Welding of Aluminum Ceased	52

Introduction

Protecting 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. Eight volumes have been published to date; the first covered data published before 1978, while the latter seven covered time periods between 1978 and December 1989. The current report includes information published between January 1990 and December, 1991. 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., bronchitis, cancer) of welding emissions are of concern. Chronic effects on other systems such as the urogenital tract have also been studied. One such effect, injury of the kidney tubules, is known to result from chronic exposure to cadmium. The effect of welding on fertility has received recent attention, but the evidence for a negative impact of welding on fertility is weak and, at the most, uncertain. Continued research in the form of epidemiologic studies, investigations with laboratory animals, and *in vitro* cell studies will help to resolve these questions.

Executive Summary

The Respiratory Tract

The contribution of welding to the development of pulmonary function deficits and respiratory disorders such as bronchitis and asthma remains uncertain, and conflicting results have been reported by different investigators. In studies which have identified a positive relationship between welding and respiratory disorders, it has not been possible to identify specific components of the exposure responsible for these conditions.

Chinn et al. (Ref. 48) and Bogadi-Sare (Ref. 31) found a statistically significant decrease in ventilatory parameters indicative of bronchial obstruction in welders. These results were in accord with those of Kilburn et al. (Refs. 111, 112) who found that reductions in lung function in welders were small, but statistically significant. Lukac et al. (Ref. 128) also found decreases in FEV₁ and FEV₁/FVC among welders, especially among those who smoked. However, non-welding controls were not examined in that study.

In contrast to these results, Melbostad and Ruud (Ref. 136), in their study of metal and machine workers, and Demers et al. (Ref. 53), in their study of boilermakers, found no association between welding and deficits in FVC or FEV₁. Rossignol et al. (Ref. 176) actually found an increase in FEV₁/FVC in experienced welders.

Inconsistent results also were seen among studies of respiratory symptoms. While chronic bronchitis was shown to be significantly related to smoking (Ref. 48), Chinn et al. (Ref. 48) and Bogadi-Sare (Ref. 31) found that it was not related to trade as a welder. However, Kilburn and Warshaw (Refs. 111 and 112) found that nearly 20% of electric arc welders had chronic bronchitis, and the incidence of this disease was related to welding, especially in nonsmokers. In other studies, welders were found to have a high incidence of chronic bronchitis (Refs. 126 and 128). Kleiner et al. (Ref. 115) found that welders developed chronic bronchitis at an earlier age and after briefer employment than mechanics. This effect was much greater in smokers than in non-smokers. Other respiratory symptoms that were studied among

welders included asthma and dyspnea. Chinn et al. (Ref. 48) and Bogadi-Sare (Ref. 31) found that breathlessness on exertion was significantly more frequent among welders. Welding was also found to be significantly associated with asthma (Ref. 11).

Cancer

The International Agency for Research on Cancer (IARC) evaluated epidemiologic studies reported through 1989 which assessed the incidence of cancer in welders (Ref. 100) and concluded that “there is *limited* evidence in humans for the carcinogenicity of welding fumes and gases.” This evaluation indicates that a “positive association has been observed between exposure to [welding fumes] and cancer for which a causal interpretation is considered...to be credible, but chance, bias, or confounding could not be ruled out with reasonable confidence.” The evidence for carcinogenicity in experimental animals was judged to be *inadequate* and the overall evaluation of IARC was that “welding fumes *are possibly carcinogenic to humans*.”

Eleven cohort and twelve case-control studies were considered by IARC in their evaluation of the cancer risk of welders. While most of the cohort studies showed a greater incidence of lung cancer among welders than among control populations, only one of these was significant (Ref. 186). Six of the case-control studies examined by IARC showed greater than a 100% excess lung risk. The excess risk was statistically significant in four of the latter studies. These four studies, served in part as the basis for the conclusion by IARC that there is limited evidence for the carcinogenicity of welding emissions in humans. Also considered by IARC was the positive association of lung cancer with exposure to welding fumes that was seen in an analysis of data pooled from 21 case-control and 27 cohort studies conducted between 1985 and 1989. The results of that analysis were published in 1991 by Simonato et al. (Ref. 184). In this large multinational investigation, the combined study population con-

sisted of 11,092 welders from 135 companies in 9 countries. Of the major causes of death, only those from malignant neoplasms were higher than expected, based on comparison with control populations. This excess was of borderline significance, and was due primarily to a significant excess of deaths from lung cancer (SMR = 134). The risk of death from lung cancer was higher in “mild steel only welders” (SMR = 178) than in “stainless steel ever welders” (SMR = 128). A statistically significant excess of bladder cancer was also observed (SMR = 191). The lung cancer incidence tended to increase with time since first exposure for the “predominantly stainless steel” group. This trend was not significant for any other group of welders. Estimated cumulative doses of total fume, total chromium, or hexavalent chromium were not significantly associated with mortality from lung cancer. The conclusions of this study were confounded by the presence of five cases of mesothelioma, indicative of asbestos exposure, in the cohort of welders. In addition, the effects of tobacco smoking could not be ruled out.

Four new epidemiologic studies of the association between cancer and welders were reported in 1991. Two of these found no cancer excesses compared with the general population (Refs. 25 and 192) and the other two studies showed an excess lung cancer incidence among welders (Refs. 69 and 178).

Fertility

Bonde conducted a series of studies concerned with the fertility of welders. In a case-control study, he showed an increased risk for subfertility (delayed conception) among 432 male welders compared with 240 nonwelding metal workers and electricians (Ref. 32). In a cohort study, Bonde et al. (Ref. 35) showed that among persons who had ever worked as welders, the probability of having a child was slightly, but significantly, reduced during the year following a year of welding exposure. The reduction in fertility was associated with the welding of mild steel, but not with SMAW or GTAW of stainless steel. Changes in sperm quality and follicle stimulating hormone were found in 35 stainless steel welders and also in 46 mild steel welders compared with 54 nonwelding metalworkers (Ref. 33). The effects were most marked among mild steel welders. Changes in semen quality were not found to be reversible, as semen quality did not improve during a 3-week welding-free vacation period (Ref. 34).

While Bonde’s studies suggest a reduction in fertility and semen quality with welding, the changes observed were slight, albeit significant. A positive dose-response was not obtained when fertility was considered in terms of years of welding exposure. Nonwelders were ex-

cluded from the large cohort study (Ref. 35) because their fertility rate was lower than that of welders during periods of nonexposure. The rationale for excluding nonwelders from the study is not clear, and it is possible that a direct comparison between the overall fertility rates among welders (including periods of both welding and nonwelding) and nonwelders would have shown no difference between the two groups.

Bonde’s conclusion that welding reduces fertility was based on differences in birthrates between periods of welding and nonwelding in the same group of welders. However, differences in the fertility of welders between periods of welding and nonwelding could have been due to factors other than welding, and a more valid comparison would be between men who were never welders and those who worked continuously as welders during their entire family-raising period. Finally, while the investigation of semen quality supported the concept that welding is associated with decreased fertility, there were some inconsistencies between the findings of the fertility and semen quality studies. As Bonde pointed out, the observed changes were small and thus subject to confounding factors which are impossible to control with human populations. Because the effects are small, controlled studies in laboratory animals may be necessary to resolve questions concerning the effects of welding exposures on fertility.

One animal study published during this report period examined the effects of chromium on male genitalia (Ref. 63). In that study, hexavalent chromium, but not trivalent chromium caused a reduction in testicular weight, a dose-dependent increase in the number of atrophic seminiferous tubules, and a reduction in the epididymal sperm count. This study is not directly relevant to fertility in welders because the route of exposure was intraperitoneal injection, the effects of which can vary markedly from those caused by inhalation.

Chromium

An important area of research involves the effects of long-term exposure to low levels of chromium. This pursuit has captured the attention of investigators concerned with industrial exposures such as welding (Ref. 36 and 219) as well as environmental exposures (Ref. 41). Drawing from the known effects of acute exposure to high concentrations of chromium on the kidney, Wedeen and Qian (Ref. 219) conjectured that long-term exposure to low levels of chromium could cause kidney tubular disease. Based on the fertility studies discussed above, Bonde postulated that long-term exposure to low levels of chromium could reduce fertility in welders. In regard to this issue, Bonde and Christensen (Ref. 36) deter-

mined chromium levels in body fluids from welders working with processes that generate fumes containing low concentrations of chromate. Chromium concentrations were significantly higher in blood and urine from stainless steel and mild steel welders than from controls. However, the concentrations of chromium in blood and urine did not change across a workshift or after a 3-week vacation break from welding. The authors found these data to be consistent with a gradual buildup of chromium in the body during long-term welding exposure. While high concentrations of chromium were found in seminal fluid from welders conducting SMAW of stainless steel, the extremely wide variation in chromium levels indicated that much of the chromium may have been derived from nonoccupational activities.

Because studies in which effects are low and difficult to detect are easily confounded by external factors unrelated to occupational exposures, it is important to be aware of nonvocational factors that could introduce error into epidemiologic studies. As part of their studies of biological monitoring of New Jersey state workers with low-level intermittent exposures to chromium in soil, Bukowski et al. (Ref. 41) determined the contribution of

avocational activities and personal habits to urinary chromium levels. They showed that males had slightly higher urinary chromium levels than did females. Beer drinking was associated with a significant increase in urinary chromium. Subjects who used tobacco, and those who had exercised within 24 hours before sampling, had slightly lower chromium levels in the urine. Neither welding nor engaging in hobby activities with possible chromium exposures was associated with increased concentrations of chromium in the urine or blood.

Coogan et al. (Ref. 50) demonstrated that lymphocytes can serve as a better biomarker than red blood cells for long-term chromium exposure. They showed that white blood cells can accumulate significantly more chromium than red blood cells. While the chromium uptake by red blood cells appeared to be independent of the valence state of the administered chromium, lymphocytes accumulated only hexavalent chromium. The investigators concluded that the exclusive accumulation of hexavalent chromium by white blood cells supports their use as target cells in the development of biomarkers for assessing exposure to chromium.

Technical Summary

The Exposure

Fumes

Using a model developed to predict the composition of welding fumes generated by SMAW and FCAW, Hewitt and Hirst (Ref. 87) showed that the flux contributes disproportionately to the mass of the fume based upon its share of the total weight of the wire. Hilton and Plumridge (Ref. 91) demonstrated that gas metal arc welding (GMAW) of stainless steel with a carbon dioxide shielding gas or stainless steel with helium as the shielding gas produced much more fumes than did GMAW with argon-based shielding gases.

When welding aluminum alloys at currents above 150 A, the FGR from an alloy containing 5% magnesium was much greater than that from a 5% silicon alloy. Chromium, nickel, manganese, and fluoride were the components most often measured in several studies of the hazardous components of welding fumes. The hazardous fume component that was most likely to reach the permissible exposure limits (PEL) during welding of stainless steel was hexavalent chromium [Cr(VI)] (Refs. 152, 194, 213, and 230).

Sutton (Ref. 194) showed that Cr(VI) produced by GMAW and gas tungsten arc welding (GTAW) of stainless steel was much lower than that from shielded metal arc welding (SMAW) of the same material. However, Olah and Pospisilova (Ref. 152) found that even though total fume production from GMAW is less than that from SMAW using electrodes with a high-chromium content, the chromium concentration in the GMAW fumes was so much higher that chromium emissions were about equal for the two processes. Although GTAW fumes contained up to 21% chromium, GTAW produced the lowest emission rate for chromium of all the methods tested. Zaks (Ref. 229) showed that manganese (from acid coatings) and fluoride (from basic coatings) were the fume components most likely to reach hazardous levels from SMAW of mild steel.

GMAW of steel coated with tin or zinc produced more fumes than welding aluminum-coated or uncoated steel (Ref. 135). Medack and Heinze (Ref. 135) calculated that air concentrations of zinc released when welding zinc-coated steel, would approach the PEL before any of the other components of the fume. Lead would be the comparable limiting factor from welding tin-coated steel. In fumes from welding aluminum-coated or uncoated steel, manganese from the electrode was the limiting factor.

Analytical Techniques. A particle-sizing method used by Ukkonen et al. (Ref. 206), combining a photometer and an electric particle counter, worked well for sizing particles with unit density but not for the denser particles of welding fumes. Battistoni et al. (Ref. 17) used a photometer to measure particle concentrations from GMAW with a continuous automatic welder. Goschnick et al. (Ref. 80) used secondary neutral mass spectrometry to measure the compositions of successive layers of welding particles. Chromium was enriched in the fume particles compared to its concentration in the electrodes. Contrary to findings of other investigators (Refs. 81 and 129), the chemical composition of the outer and inner layers of the particles did not vary.

Lasers

Lasers used for welding are usually class IV, the most hazardous rating, and require safety features to prevent exposure. Ordinary welding curtains are not suitable for protection against the energy of the laser beam, and special laser barriers must be used. A useful feature that can be incorporated into these barriers is a surface coating that shows visual signs of exposure to stray laser beams (Ref. 221). The electrical power supplies and the chemicals used with lasers also present hazards in the workplace, as do the fumes generated by welding with lasers (Ref. 109). Engel et al. (Ref. 60) found that more fumes

were released while cutting stainless steel with CO₂ lasers than while cutting nonalloyed steel. The fume particles were spheres and agglomerates of spheres of sub-micrometer size, and their composition was similar to that of the metal being cut.

Electromagnetic Fields

Electromagnetic fields (EMFs) are produced by the power sources used in all types of electric arc welding. Although it is not clear that EMFs from welding pose a health hazard, it has been suggested by Zyubanova et al. (Ref. 232) that their intensity may be diminished by the use of coaxial cable to minimize the distance between the electric power lines.

Incidental Exposures

Henriks-Eckerman et al. (Ref. 84) developed a sampling procedure for monitoring workplace pollutants arising from production coatings on the metal surface. The procedure, which included a chemisorbent tube for aldehydes and a tube of adsorbent resin preceded by a glass fiber filter for particulates and condensable organic chemicals, was used to monitor the exposure of metal workers to paint degradation products generated by welding, flame cutting, and straightening painted steels in a Finnish shipyard (Ref. 61).

Onodera et al. (Ref. 157) measured emissions of radioactivity during the decommissioning of a Japanese nuclear power plant. Generally, cutting with a welding torch produced less radioactivity than cutting with mechanical tools. Cutting under water reduced radioactive emissions to an even greater extent. Carmichael and Haynes (Ref. 46) described safety practices and exposure measurements during repairs to apparatus contaminated with tritium at a Canadian nuclear power plant.

Hygiene and Work Practices

Equipment. Using computer simulations and laboratory data, Tum Suden et al. (Ref. 205) showed that the parameters of hood design and operation that affected breathing zone concentration are flow rate through the hood, hood aspect ratio, and the welder's position relative to the hood. Jakubcik (Ref. 102) reported that ventilation was improved during tack-welding of long pieces by enclosing the work in a segmented hood which could be opened in the area where the work was being performed. For gun-mounted fume collection devices, the position of the exhaust vents is important in determining collection efficiency (Ref. 51). A welding table designed by

van der Veen and Regensburg (Ref. 210) combined efficient ventilation, absorption of ultraviolet (UV) radiation, and height adjustments to prevent muscular stress.

Protective Gear. Two devices employing activated carbon filtration were shown to be effective in reducing ozone concentrations in the breathing zone (Ref. 193). Several types of material were found to provide superior heat protection to asbestos, but some of the flame-proof clothing tested lost resistance to ignition after 10 or 20 washings (Ref. 105).

Accidents. Analysis of accidents fatal to welders showed that the welding apparatus was not often implicated. Most of the fatal accidents analyzed by Trent and Wyant (Ref. 203) were due to welders falling or being struck by falling objects and to environmental hazards in the workplace. Three fatal accidents involving falls were described by the National Institute of Occupational Safety and Health in 1990 and 1991 (Refs. 146-148). Rekus (Ref. 169) reviewed several cases of fatal accidents to workers entering confined spaces. Tanks and holds that have been recently opened after having been sealed for long periods are particularly hazardous due to accumulation of toxic gases or depletion of oxygen.

Stress. Physiological stresses to welders were documented in two studies in 1990 and 1991. Valente and Chiapperini (Ref. 209) and Richter (Ref. 170) measured pulse rate, blood pressure, oral and skin temperature, and perspiration rate in four welders and related the results to working conditions. Psychological stresses among welders were attributed by Richter (Ref. 170) and Hyytiainen and Uutela (Ref. 97) to the tediousness of the work, the constant need for exercising caution, and the isolation of the worker in the welding environment. Gerhardtsson (Ref. 75) found that welders reported a combination of high work load and little opportunity to influence the work situation, which has been related to some physical manifestations of stress.

The Effects of Welding on Human Health

Respiratory Tract

Pulmonary Function and Bronchitis. Welders were included in seven studies of lung function and respiratory symptoms. Chinn et al. (Ref. 48) found significant associations between trade as a welder and development of breathlessness upon minimal exertion. A decline in the lung function parameter FEV₁ was related to occupation

as a welder or caulker/burner and to atopy (positive response to skin tests with common allergens).

Bogadi-Sare (Ref. 31) found a significant decrease in FEV_1 and FEV_1/FVC among 47 stainless steel welders and 59 nonwelders employed in machining and polishing stainless steel. The frequency of chronic bronchitis was the same in exposed and unexposed workers, but the exposed group had significantly more frequent complaints of dyspnea and choking. In a community study which included 84 welders, Bakke et al. (Ref. 10) found welding to be significantly related to chronic obstructive lung disease and asthma.

Kilburn and Warshaw (Ref. 111) found small, but significant deficits in FEV_1 , FEF_{25-75} , and FEF_{75-85} in 291 male welders compared with historical controls from the same geographical area. In a second study, Kilburn et al. (Ref. 112) found that the rate of chronic bronchitis was substantially elevated in gas tungsten arc welders and was unrelated to smoking. There was a small but significant reduction in FVC, FEV_1 , and FEF_{25-75} in smoking welders compared to the reference population while only the FEF_{25-75} was reduced in nonsmoking welders. Further tests showed that changes in lung function do not occur during a workshift in workers exposed to stainless steel welding fumes.

Lukac et al. (Ref. 128) found deficits in FEV_1 and FEV_1/FVC that were related to duration of exposure in welders of steel bridge components. This study did not have nonwelding controls. Melbostad and Ruud (Ref. 136) found no difference in lung function (FEV_1/FVC) between welders and machinists, but work-related respiratory symptoms were more prominent among welders. Contrary to the findings of most other studies, Rossignol et al. (Ref. 176) found a significant increase in FEV_1/FVC with length of employment as a welder or burner.

Kleiner et al. (Ref. 115) found significantly more chronic bronchitis among welders (24.3%) than among mechanics. Demers et al. (Ref. 53) studied asbestos-exposed boilermakers and did not find a positive relation between welding and respiratory disease or changes in lung function. Lubianova et al. (Ref. 127) found a 35% incidence of signs of chronic bronchitis among welders, related to years of exposure, age, and smoking.

Case Reports. Three of the 35 cases of occupational asthma reported to the Ministry of Labor in Singapore between 1983 and 1990 were welders. The prevalence of smoking and the percentage who reacted positively to environmental allergen skin prick testing were not significantly different from controls (Ref. 121).

Lasfargues et al. (Ref. 120) described a case of siderosis and interstitial fibrosis in a man who had welded for 30 years. Wagner et al. (Ref. 217) described post mortem findings of pneumoconioses, chronic tracheobronchi-

tis, and massive emphysema in the lungs of a man who had worked as an arc welder for 15 years. Chemical analysis of his lung tissue revealed excessive concentrations of iron, aluminum, chromium, nickel, manganese, and copper. Pneumoconiosis and asbestosis lesions in the lungs of a welder examined by Kishimoto et al. (Ref. 113) were considered to provide an ideal culture medium for a Mycobacterial infection which was present in the patient's lung.

Cancer

Lung Cancer. The International Agency for Research on Cancer (IARC) concluded that welding fumes are possibly carcinogenic to humans, based upon limited evidence in humans and inadequate evidence in experimental animals (Ref. 100). Included in the data considered by IARC was the analysis of a pool of 21 case-control studies and 27 cohort studies published in 1991 by Simonato et al. (Ref. 184). That analysis showed a significant excess of lung cancers (Standard mortality ratio: SMR = 134) among welders.

Four new epidemiologic studies of the association between cancer and welders were reported in 1991. Becker et al. (Ref. 25) found a significant excess of deaths from all malignancies among welders when compared with machinists in the same plant in the Federal Republic of Germany (Relative risk = 1.6). However, welders did not have a significantly elevated risk of lung cancer when compared to the general population. In an American study (Ref. 192), limited to mild steel welders who had no asbestos exposure, lung cancer was not associated with welding when welders were compared with either the general population or to nonwelders in the same plants. Analysis of cancer registry data (1971 to 1980) in Finland found a statistically significant increased risk for lung cancer among welders (Standardized Incidence Ratio = 150) (Ref. 178). Similarly, the 125 lung cancer deaths of welders in British Columbia between 1950 and 1984 were significantly greater than expected (Proportional Mortality Ratio = 129), compared with the general population and to a subgroup of skilled manual workers. Significantly greater risks were also found for Hodgkin's disease and all cancers in that study (Ref. 69).

Cancer at Other Sites. Ahrens et al. (Ref. 2) found that nasal and laryngeal cancer were strongly linked to smoking and alcohol consumption but not to welding. Yu et al. (Ref. 227) identified exposure to combustion products among risk factors for nasopharyngeal carcinomas. In this exposure group, 15 cases and eight controls were exposed to welding fumes, but the significance of these numbers was not reported. Bladder cancer was found to be significantly elevated in the combined study population analyzed by Simonato et al. (Ref. 184), but the

incidence of cancer was unrelated to duration or intensity of exposure.

Cancer in Children of Welders. A heritable form of retinoblastoma, a tumor in the retina occurring in young children, was linked to father's occupation in the metal-working industry. The nonheritable form of the disease, believed to be the result of post-conception exposures, was linked to fathers working in a job cluster that included welders, machinists, and paper-processing workers (Ref. 43). Welders were not analyzed separately in either study so that the contribution of welding exposures to this disease cannot be assessed.

Cancers Associated with Electromagnetic Fields. Five epidemiological studies of the incidence of leukemias and cancer of the central nervous system reported in 1990 and 1991 included welders in the exposed population. Leukemia was linked to exposure to electromagnetic fields (EMFs), but not to welding, in three studies, (Refs. 16, 106 and 201) and no relationship was found between the risk of leukemia and exposure to EMFs in the second study (Ref. 158). EMF exposure was implicated in central nervous system cancer in three studies (Refs. 68, 106 and 201). Although the data for welders were analyzed separately in all three studies, only one indicated a link between welding and central nervous system cancer, and that was of borderline significance (Ref. 201).

Cancers Associated with Ultraviolet Radiation. Holly et al. (Ref. 93) conducted a case-control study of the association between uveal melanoma and exposure to UV light. A statistically significant relative risk for uveal melanoma was found among persons included in a group who had experienced welding burn, sunburn of the eye, or snow blindness.

Metal Fume Fever

A typical case of metal fume fever was described by Heydon and Kagan (Ref. 88). The patient developed a cough, chills, cramps, and difficulty breathing 2 hours after cutting galvanized steel with a gas torch without using a mask.

Based on the hypothesis that polymorphonuclear leukocytes (PMNs) responding to inhaled zinc oxide fumes release mediators (cytokines) that can elicit the systemic effects characteristic of metal fume fever, Blanc et al. (Ref. 27) analyzed the white blood cell population and concentration of two cytokines (interleukin-1 and tumor necrosis factor (TNF) in bronchoalveolar lavage (BAL) fluid following exposure of experienced welders to fumes generated by welding galvanized mild steel. While the population of inflammatory cells increased in

the BAL fluid during the first 22 hours after welding, little or no TNF or interleukin-1 was detected. The investigators concluded that they had examined the wrong cytokines and postulated that other cytokines, or a cytokine-like mechanism, may mediate the syndrome of metal fume fever.

Effects on the Ear

Thirty cases of burns to the ears inflicted by flying sparks from welding operations were discussed by two investigators (Refs. 64 and 137). Fisher and Gardiner (Ref. 64) ascribed these injuries to the lack of ear protection afforded by "visor" type helmets when working overhead or in cramped conditions with the neck flexed.

Effects on the Eye and Vision

Using a theoretical model of the human eye, Okuno (Ref. 151) concluded that infrared (IR) cataracts result from heat conduction to the lens following absorption of IR radiation by the cornea. The threshold IR irradiances for cataract formation were determined to be in the range of 163 to 178 mW/cm² for exposures lasting longer than 5 minutes under normal conditions. To protect against cataract formation, Okuno recommended that IR irradiance be limited to 80 mW/cm² for exposures over 5 minutes.

Four cases of welders with cataracts were described by Hanke and Karsten (Ref. 83). The IR irradiance received by the eyes of each of the welders was estimated from detailed occupational histories and reconstruction of their workplace routines. All four welders had routinely been exposed to doses of IR radiation in excess of the maximum safe limits recommended by Okuno (Ref. 151).

An unusual case in which a welder developed bilateral maculopathy (retinal injury) in the absence of photokeratitis, following unprotected exposure of less than two minutes' duration to a SMAW unit was described by Power et al. (Ref. 166). The investigators suggested a link between the severity of the retinal lesions in the absence of keratitis with the drug fluphenazine, which the patient had taken for 10 years for treatment of depression. They postulated that fluphenazine accumulates in the retinal pigment epithelium, where it acts as a photosensitizing agent, making the retina particularly susceptible to photochemical damage. Neki (Ref. 144) questioned the assumptions made by Power et al. and suggested that, in the absence of experimental proof, it is just as likely that the fluphenazine accumulates in the cornea where it provides protection against the action of electromagnetic radiation.

Surveys of persons appearing in hospitals with eye injuries showed that 17% of the patients treated for eye injuries in a Hospital in Denmark were welders (Ref. 9) and 11.5% of those treated for ocular foreign bodies during a six month period in a hospital in England were welders (Ref. 13). A survey of welders conducted by Ten Kate and Collins (Ref. 198) related eye injury to the use of appropriate eye protection. Forty percent of the welders reported "receiving at last one welding flash". Reports of eye symptoms (e.g., tired, sore, watery or itchy eyes) correlated well ($p < .001$) with the number of flashes received. Unprotected exposure to nearby welding was experienced by 64% of the welders.

Narda et al. (Ref. 142) found that the frequency of chronic conjunctivitis was substantially higher among welders than controls who worked in a foundry in Italy. The incidence of conjunctivitis was higher in welders who used SMAW than in those using submerged arc welding (32.4%). Norn and Franck (Ref. 149) found that spheroid degeneration (small globular, yellowish lesions on the exposed part of the conjunctiva or cornea), was more common in welders than in other workers. A significant, but much smaller increase in the incidence of pinguecula (yellow spots on the exposed conjunctival bulbi) was also noted.

Effects on the Skin

Two cases were described in which welders reacted to reflected UV radiation. The first case involved a welder who developed recurrent mild facial erythema. His condition was attributed to UV radiation reflected from a white textile hood that he wore in addition to a helmet (Ref. 92). A second welder developed facial dermatitis associated with welding. Skin testing showed an abnormal reaction to UV radiation. A shield was used while welding, so his dermatitis was ascribed to indirect exposure to UV radiation (Ref. 226).

Effects on the Nervous System

Sjogren et al. (Ref. 189) conducted a study of neuropsychiatric symptoms among 65 welders who welded primarily aluminum and 217 railroad track welders. Subjects who welded aluminum, lead, or manganese for long periods experienced significantly more neuropsychiatric symptoms than welders exposed to chromium or nickel. Depression and difficulty concentrating were associated with exposure to aluminum fume. Short memory, forgetfulness, and frequent headache were associated with welding lead-painted steel. Experiencing painful tingling sensations was associated with exposure to manganese fume.

Wechsler et al. (Ref. 218) conducted a pilot study to evaluate a range of occupational and environmental agents for potential associations with Parkinson's disease. The study compared 34 Parkinson's disease patients (average age 68.4 years) with 22 neurology clinic patients (average age 58.9 years) having diseases other than Parkinson's disease. Analysis by metal exposure in males indicated more frequent exposures to aluminum and copper. Three of the male Parkinson's disease patients and none of the controls had been employed as welders. The three welders reported exposures to aluminum but not to other metals.

Armon et al. (Ref. 7) conducted a case-control study to evaluate risk factors for amyotrophic lateral sclerosis (ALS). Men with ALS had spent significantly more time welding or soldering than controls ($p < 0.01$).

Effects on the Immune System

Ulrich et al. (Ref. 207) found significant changes in humoral immunity in welders; immunoglobulin IgG increased, and IgM decreased with the duration of welding. The serum indicators of inflammation, complement and alpha-1-antitrypsin, changed significantly with the number of years welding experience.

Effects on the Musculoskeletal System

Torner et al. (Ref. 200) found that the incidence of neck and/or shoulder symptoms was more prevalent among welders than clerks from the same plant. The range of motion in external rotation of the shoulders was significantly less among the welders than the clerks and almost half (47%) the welders had atrophied shoulder muscles. Most of the welders (60%) considered their symptoms to have been caused by heavy work for a prolonged time, while only 12% attributed their musculoskeletal symptoms to a sudden incident at work.

Prolonged or awkward working postures and incorrect heavy lifts and stumbling or falling were found to be the major risk factors for accidents involving lower back injuries in welders (Ref. 96). In addition, certain stress factors, (i.e., hurry, monotony, and an accelerated working pace) were also related to lower back pain (Ref. 97). Occupationally related lower back pain was infrequently related to sudden movements.

Jarvholm et al. (Ref. 103) used electromyography and simultaneous measurement of intramuscular pressure to study the effectiveness of arm support in reducing the load on the supraspinatus muscle of the shoulder during simulated welding operations. It was determined that arm support greater than 2.2 to 3.4 pounds (force) would

be needed to reduce intramuscular pressure sufficiently to lower the incidence of shoulder pain and impairment.

Marciniak and Badowski (Ref. 132) compared spinal X-rays among job applicants and experienced manual workers in a Polish automobile factory and found that the incidence of scoliosis was highest among workers in jobs that imposed the greatest spinal loading, i.e., tinsmiths, pressers, and welders.

Carpal tunnel syndrome (CTS) can result from repetitive wrist movement tasks such as welding (Ref. 160) or from use of vibrating hand-held tools (Ref. 82). Hagberg et al. (Ref. 82) found that welding was one of the four most common occupations among patients with carpal tunnel syndrome. Panio (Ref. 160) described a workplace program for the prevention of CTS that included pre-employment screening; worker training; modification of job routine to reduce unnatural angles of the wrist; modification of tools; and gloves or braces to maintain correct wrist alignment.

Effect on the Kidneys

Cadmium. Trevisan and Maso (Ref. 204) examined the reversibility of proteinuria in six cadmium-exposed welders. All of the subjects had worked in shops where brazing was performed with high-cadmium alloys and had participated in an earlier study of urine proteins before they ceased welding in 1982. Three of the subjects had no indications of low molecular weight proteinuria before they had ceased welding and their urinary protein levels remained low during the 5-year follow-up period. The remaining three welders had shown low molecular weight proteinuria, indicative of kidney tubular dysfunction, while still exposed to cadmium. During the follow-up period, beta 2-microglobulinuria increased in two of these welders, while in the third there was a temporary increase in beta 2-microglobulinuria which returned to normal levels after 5 years of nonwelding. These results indicate that cadmium-induced tubular dysfunction is reversible in some, but not all, persons with this condition.

Chromium. While acute kidney disease can result from massive exposure to chromium, chronic renal disease resulting from occupational or environmental exposure to chromium has not been reported. Wedeen and Qian (Ref. 219) maintained that the effects of chronic chromium exposure on the kidneys have not been adequately studied. He stressed the need for large-scale, prospective case-control epidemiologic studies to demonstrate whether or not delayed renal effects can result from low-level, long-term exposure to chromium.

Fertility

Boshnakova and Karev (Ref. 37) found that spontaneous abortions occurred significantly more frequently in the families of welders and that still births occurred significantly more frequently in families of nonwelding manual control workers.

Bonde (Ref. 32) observed an increased risk for subfertility (delayed conception) in a case-control study of 432 male welders and 240 nonwelding metal workers and electricians. In a continuation of that study, Bonde et al. (Ref. 35) examined fertility in a Danish cohort of 3702 male metalworkers. Among subjects who had ever welded, the probability of fathering a child during years when they were not welding was significantly greater than that of metalworkers who had never welded. Among persons who had ever worked as welders, the probability of having a child was slightly, but significantly, reduced during the year following a year of welding exposure. The reduction in fertility was associated with the welding of mild steel but not with SMAW or GTAW of stainless steel.

Bonde (Ref. 33) compared semen quality and serum levels of sex hormones among 35 stainless steel welders, 46 mild steel welders and 54 non-welding metalworkers. Changes in sperm quality and follicle stimulating hormone were seen in both groups of welders. Effects were most marked among mild steel welders. To determine if the changes in semen quality were reversible, semen quality was examined in 19 of the mild steel welders, 18 of the stainless steel welders and 16 of the non-welding metalworkers before and after a 3-week, welding-free vacation period (Ref. 34). No significant improvements in any of the semen parameters were observed at any of the post-vacation measurements relative to the pre-vacation values.

Effects on the Teeth

Tatintyan and Abgaryan (Ref. 197) reported that 87% of welders have some degree of periodontal disease and gingivitis. They correlated this with a lower than normal concentration of lysozyme, an enzyme destructive to the cell wall of some bacteria, in saliva collected from the welders. These investigators developed a small filtration device to protect the mouth from exposure to welding fumes. After using the device for 2 years, lysozyme increased in saliva collected from welders.

Effects of Specific Metals

Beryllium. A typical case of chronic beryllium disease was described by Monie and Roberts (Ref. 138) in a

fifty-one-year-old Scottish welder who had a long-standing cough with morning production of mucoid phlegm. His chest X-ray showed reticulo-nodular shadowing. Examination indicated reduced pulmonary function and biopsies showed mild fibrosis and epithelioid cell granulomas. Beryllium was identified in biopsied lung tissue.

Cadmium. Yates and Goldman (Ref. 225) described a case of acute cadmium poisoning which occurred following two weeks of brazing ship propellers with an oxy-acetylene torch using an alloy containing 20% cadmium. After 10 days, the patient began to experience malaise and breathlessness, developed fever and joint pain, and had reduced lung function.

Fuortes et al. (Ref. 67) described an acute fatality in a man who was using a propane torch and soldering gun to join sheet metal surfaces. He died 3 days after developing an extremely high fever, cough, and abdominal pain. Autopsy revealed pulmonary edema and congestion. Exceedingly high cadmium levels (280 ng/ml) were detected in his blood and milligram quantities of cadmium were identified on the soldering gun tip and sheet metal samples with which he had been working.

Iron. Lubianova (Ref. 126) found that the concentrations of iron and transferrin were elevated in the blood of welders. Welders without pneumoconiosis had less blood iron than welders with pneumoconiosis.

Biological Monitoring

Chromium: Biomarkers. Popp et al. (Ref. 165) examined DNA integrity in blood lymphocytes obtained from 39 stainless steel welders and 18 controls. The average sister chromatid exchange (SCE) frequency was significantly lower for welders than controls. However, alkaline filter elution indicated the presence of DNA-protein cross-links which showed that SCE analysis alone could lead to the false impression that DNA integrity remains intact in chromium-exposed workers.

Coogan et al. (Ref. 50) investigated whether chromium concentrations in lymphocytes can be used as a biomarker for long-term chromium exposure. White blood cells accumulated significantly more hexavalent chromium than did red blood cells. Chromium was undetectable in white blood cells, and present in only low levels in red blood cells, after administration of trivalent chromium to rats. The investigators concluded that the exclusive accumulation of hexavalent chromium by white blood cells supports their use as target cells in the development of biomarkers for assessing exposure.

Chromium: Biological Monitoring. Biological monitoring of low-level chromium exposures was studied by two investigative groups (Refs. 36 and 41). Bonde and Christensen (Ref. 36) examined absorption and clearance kinetics following low-level exposure to chromium in 39 welders and 18 controls. While blood and urine chromium concentrations were significantly higher in stainless steel and mild steel welders than in controls, there were no significant changes in chromium levels during the work week, and urine and blood chromium concentrations did not change during a 3-week break from welding. The investigators found these data to be consistent with a gradual buildup of chromium during long-term welding exposure.

Bukowski et al. (Ref. 41) examined factors which could confound studies of the absorption kinetics of chromium in workers who experienced low-level, intermittent exposures to soils heavily contaminated with chromium. They focused on determining nonvocational factors which could introduce errors into biological monitoring data. Males had slightly higher urinary chromium levels than did females. Beer drinking was associated with a significant increase in urinary chromium, while tobacco use or exercise caused a slight decrease in urinary chromium levels. Neither welding nor engaging in hobby activities with possible chromium exposures was associated with increased concentrations of chromium in the urine or blood.

Nickel. Angerer and Lehnert (Ref. 5) determined nickel levels in red blood cells, plasma, and urine from 103 stainless steel welders who worked with chromium-nickel alloyed steel. The authors calculated that urinary nickel levels between 30 and 50 µg/L correspond to an external exposure of 500 µg/m³.

Aluminum. Elinder et al. (Ref. 59) measured aluminum levels in bone and urine from two workers 5 years after they had ceased routine welding of aluminum. The investigators concluded that aluminum accumulates in the skeleton and tissues following long-term inhalation exposure and that the elimination of retained aluminum is very slow, on the order of several years.

Zinc. Chughtai et al. (Ref. 49) showed that zinc concentrations were significantly higher in serum from gas and arc welders than from controls.

Incidental Exposures

Degreasing Agents. Two incidents were described in which photochemical decomposition products resulting from reaction of degreasing agents with UV radiation produced by GMAW or GTAW may have caused respira-