Effects of Welding on Health, VIII

American Welding Society

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

Effects of Welding on Health VIII

Research performed by Southwest Research Institute, San Antonio, Texas, under contract with the American Welding Society and supported by industry contributions.

This is an updated (January 1988–December 1989) 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 1993

Abstract

This literature review, with 193 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 exposure to fume, while Section 2 contains information related to the human health effects of exposure to electromagnetic radiation. Section 3 discusses studies of the effects of welding emissions from production coatings, and Section 4 describes hygiene and work practices. The remaining sections are devoted to reports on health studies on affected organ systems.

Prepared for
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International Standard Book Number: 0-87171-437-X

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Foreword

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

This literature review was prepared for the Safety and Health Committee of the American Welding Society to provide an assessment of current information concerning the effects of welding on health, as well as to aid in the formulation and design of research projects in this area, as part of an on going program sponsored by the Committee. Previous work consists of the reports Effects of Welding on Health I through VII 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:

Institute of Scientific Information, Inc.
3501 Market St.
Philadelphia, PA 19104
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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 3.0, *Standard Welding Terms and Definitions.*

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

EWH — VIII		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
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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.

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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. Seven volumes have been published to date; the first covered data published before 1978, while the latter six covered time periods between 1978 and December 1987. The current report includes information published between January 1988 and December 1989. 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 effects of electromagnetic radiation, covered in Section 2, are not yet completely understood and more research is needed. The respiratory tract, the primary route of exposure to welding emissions, is also a major target organ of many components of these emissions as noted in Section 5. Acute effects (e.g., metal fume fever in Section 7), as well as potential chronic respiratory effects (e.g., cancer in Section 6) of welding emissions are of concern. However, the risk of cancer from these exposures has not been clearly established, and more research in the form of epidemiologic studies, investigations with laboratory animals, and in vitro genotoxicity studies will help to resolve this question.

Executive Summary

Welding and related technologies require active risk management to mitigate the well known, and not so well known, effects of exposure to chemical and physical agents. This survey of the literature related to the effects of welding and health covers the calendar years 1988 and 1989.

Several of the epidemiologic studies identified a synergistic interaction between cigarette smoking in populations exposed to welding fumes and lung cancer. Workplace smoking policies may eventually become an especially important part of occupational hygiene programs in industries using welding.

Electric and magnetic fields are identified as a new physical agent exposure which may eventually need to be controlled. It is entirely possible that regulation relating to electric and magnetic field exposures may arise from concerns of residential exposure and eventually impact the welding industry.

Ironically, a technology which may reduce human exposure to welding emissions, the use of robots, may increase the possibility of other threats to health and welfare such as crushing injuries.

Tenuous connections with parental occupations in groups of activities which include welding or soldering have been identified in studies of childhood cancer. This general area of research may well have more specific investigations of welding in the future, because of the potential for exposure to metals.

Regulatory changes occurred world-wide in 1988–89. The general tone of the regulations is toward reduction of exposure to hazardous materials to the minimum attainable levels. Effective management of risk will require implementation of management systems to facilitate and monitor worker compliance.

Advances in biological monitoring, especially for metals, and systems for the physical analysis of welding emissions make it reasonable to predict that, within the next few years, it will be possible to monitor exposure and assess the effectiveness of engineering controls.

Technical Summary

The Exposure

Fumes

Fumes from welding processes are usually complex mixtures, the composition of which is usually different from the composition of the electrode or consumables. Fume components are generated by volatilization, reaction, or oxidation of the materials involved in the process including the consumables, the base metal and its coatings and other materials present in the atmosphere at the welding site (Ref. 166).

The potential hazards associated with exposure to the components of welding fumes are recognized, and work practices for the minimization of exposure are included in materials on welding safety (Ref. 165) and a consensus standard on welding and cutting safety, ANSI/ASC Z49.1-88 (Ref. 1). Ventilation equipment for welding fume control is also the subject of a consensus standard, ANSI/AWS F3.1-89.

One approach to reducing the potential health hazards from welding fumes is modification of the consumables. A carcinogen, hexavalent chromium, Cr(VI), is normally present in fumes when welding stainless steel, but a low-fume electrode described by Griffiths and Stevenson (Ref. 58) is reported to give an almost 10-fold reduction in Cr(VI) concentration in the fume.

Fume composition is a function of many factors which interact in a complex manner. For example, a sample of hardfacing and surfacing wires had nearly a 5-fold difference in fume particulates, but the testing was performed at only one load point per wire (Ref. 64) which gives an incomplete picture.

Despite the information available on safety and ventilation and the research on processes and supplies, actual workplace fume concentrations may exceed acceptable levels (Ref. 45).

Gases

The gases which may be generated during welding processes include ozone, carbon dioxide, fluorides, carbon monoxide and oxides of nitrogen (Ref. 165). One approach to the reduction of ozone and nitrogen dioxide emissions from GTAW may be to add a low concentration of nitric oxide to the shielding gas (Ref. 10).

Carbon monoxide concentrations measured with personal samplers and the difference in carboxyhemoglobin levels between cigarette smokers and nonsmokers is a function of the work environment. For outside work, smokers had a 2- to 3-fold higher concentration of carboxyhemoglobin. For inside work, the absolute levels were higher, and the smokers and nonsmokers had similar blood carboxyhemoglobin levels (Ref. 169)

Electromagnetic Energy

Many wavelengths of electromagnetic radiation are involved in welding processes. The hazards of ultraviolet light are addressed by guides for lens shade selection such as the consensus standard ANSI/AWS F2.2-89 (Ref. 14). Lasers have important differences from conventional processes, and there may be diffuse reflection hazards near the target (Ref. 140).

Extremely Low-Frequency Electromagnetic Energy (ELF)

Concern about the potential health effects of very low levels of nonionizing radiation, usually in the context of the A.C. power system, has implications for users of electric arc welding processes. Although the area is controversial and the connection to adverse health outcomes is inconclusive (Ref. 176), it is clear from exposure studies (Ref. 161) that electric arc welding can cause relatively high levels of exposure.

Production Coatings/Paints

Characterization of the organics released in fumes can differentiate the profiles associated with different types of production coatings (Ref. 48) which may lead to lower risk production coatings.

Lead-based paints are used as a coating on structural steel and may be a significant source of lead exposure even in outdoor welding or cutting operations (Ref. 138).

Hygiene and Work Practices

Robotic welding systems have the potential to reduce human exposure to potentially toxic materials, but they also bring the need for new safety considerations involving aspects ranging from mechanical interlocks and software issues (Ref. 132).

Fatal accidents related to welding and cutting ranged from 10 to 39 per year between 1975 and 1985. Over half of the fatalities in general industry were related to fires or explosions, or both. The compilation by Cloe (Ref. 36) includes 217 case files involving 262 fatalities which provide a narrative description of the incident as well as useful summary tables, some of which are reproduced in the corresponding section of this document.

Effects of Welding on Human Health

Respiratory Tract

Alveolar Macrophages. Tissue culture studies of the effects of fumes from different welding processes on bovine macrophages and soluble Cr were reported by Hooftman, Arkesteyn, and Rosa (Ref. 67). In this study, most of the cytotoxicity of the fumes sampled could be explained by their soluble chromium content. Fume particles obtained from MIG-MS were similar to those for inert glass beads and particles from MMA-SS were the most toxic in this assay.

Anti-oxidant Systems. Study of aluminum welders by Pierre et al. (Ref. 133) showed changes in serum ceruloplasmin levels through the work week in "confined space" welders. The authors suggest that ceruloplasmin is being consumed as part of the extracellular long antioxidant system and that this process influences serum levels.

Retained Particles. Magnetopneumography by AC susceptibility bridge methods (Ref. 159) can provide information about total lung magnetic particulates. An alternative method is SQUID (superconducting quantum interference device) measurements of the magnetic signal from particles magnetized by an external magnetic field (Ref. 157). These small studies demonstrate the possibility of these measurements.

Pulmonary Function and Bronchitis. An interaction between welding and smoking on pulmonary pathology was reported in several studies (Refs. 30, 59, 77, and 78). The general finding is that welders have a higher rate of pulmonary pathology than nonwelders and that welders who smoke have higher rates than welders who did not smoke.

Cancer. Welders were the subjects in seven cancer epidemiology studies and appear as a class of workers in several occupational survey studies. Cigarette smoking and exposure to asbestos are confounding variables which can obscure the relationship to welding processes per se. Evidence is accumulating that the relationships between welding process and cancer are complex. Tola (Ref. 168) studied mild steel welders who had not been exposed to Cr(VI) fumes in a large study (1689 welders). Welders had a small but not statistically significant elevated risk for lung cancer. Merlo et al. (Ref. 102) who reported that oxyacetylene welders have an excess risk of respiratory tract cancer, but arc welders did not. They propose that this difference is accounted for by differences in the type and level of exposure to fumes and polycyclic aromatic hydrocarbon exposure because of work inside oil tankers. These studies provided evidence that specific characteristics of the welding environment may be associated with cancer.

Welding has been identified in classes with many other occupations as a parental job factor in childhood cancers: Wilm's tumor (Ref. 29), brain cancer (Ref. 185), and liver cancer (Ref. 28). These studies use very general occupational categories and are not specific to welders; however, they do suggest variables for studies of the children of welders.

Metal Fume Fever

While zinc fume fever is usually transient (Ref. 85), inhalation of cadmium fumes can produce severe illness (Ref. 123).

Effects on Hearing

Some combinations of welding technology and process parameter values can produce sufficient noise such that an exposure of 1 hour reaches the maximum permissible noise exposure criterion (Ref. 54).

Effects on the Eye and Vision

Despite safety recommendations and guidelines, retinal injuries occur in developed countries (Ref. 25). In a study of workmen's compensation claims in Canada, 72% of welder's eye injury claims resulted from foreign body injuries (Ref. 137).

Effects on the Nervous System

Although most welding-related nervous system effects involve incidental chemical exposure such as hydrogen sulfide (Ref. 170) or aliphatic hydrocarbons (Ref. 66), Rudell et al. (Ref. 144), studied welders who reported dizziness after welding with a battery of oculomotor tests and found that a small sample of welders had lower scores than controls which decreased further after only 30 minutes of welding.

Effects on the Musculoskeletal System

Work position (Ref. 164) may be a contributory factor in development of musculoskeletal complaints, and it is possible that ergonomic studies (Ref. 146) and workplace interventions (Ref. 183) will reduce musculoskeletal complaints.

Effects on the Reproductive System

A questionnaire and semen analysis study by (Ref. 109) did not detect a strong relationship between welding and "poor sperm quality" and the summary of a Danish review article (Ref. 18) suggests because of methodological problems with studies showing a relationship between sperm quality and welding, further research is required

Effects on the Urogenital Tract

Although both welders and platers had elevated levels of urinary Cr (Ref. 174), this study examined a variety of biochemical markers of kidney function and found little evidence of pathology from Cr(VI) exposure.

Effects on the Immune System

An immune system screening of welders with immunoglobulin measurements and intradermal challenges (Ref. 19) led the authors to conclude that a significantly higher proportion of welders had signs of deficiency of cell-mediated immunity.

Biological Monitoring

A two-compartment model is suggested by Sjogren et al. (Ref. 152) to account for urine aluminum levels. One compartment, perhaps the lungs and skeleton, has a long half life and is related to years of exposure. The other component has a short half-life and is related to current air Al concentration.

Welding processes which involve Cr are associated with uptake and increased urinary excretion (Ref. 108) but the urinary Cr does not reflect the oxidation state of the exposure source because Cr(VI) is reduced to Cr(III) in blood (Ref. 105).

Toxicologic Investigations In-Vivo and In-Vitro

In vitro studies of fume samples in tissue culture cytotoxicity assays with kidney or embryo primary cells (Ref. 160), macrophages (Ref. 67), or sister chromatid exchanges in ovary cells all suggest that the soluble Cr(VI) is the major contributor to the cytotoxicity observed.

In vitro studies on cultured cells of the effects of vanadium (Ref. 74) showed changes with hyperbaric pressure.

Conclusions

Many of the potential effects of welding on health are related to specific chemical or physical agents involved in the welding process. These welding factors range from components of welding fume to electromagnetic radiation. In general, management of these risks can be accomplished by appropriate industrial hygiene practices, once the risk factor is identified and exposure is controlled.

Some risks to welders are work-related secondary factors that do not result from the welding process itself but are a part of the occupational setting. Examples of these types of risks are asbestos exposure during shipyard welding and industrial accidents involving falls. Industrial hygiene and safety practices target the reduction of these secondary risks.

Personal risks are those which occur within an individual's lifestyle without regard to occupational setting. Examples of personal risks include cigarette smoking, "Type A" personality characteristics, and driving while intoxicated.

Welding-process, occupational, and personal risk factors occur in combination in individual workers and complicate the process of risk assessment. Welding is a complex chemical and physical process which makes the process of risk assessment (and consequently, risk management) especially difficult. The complex nature of the potential exposures and the combination of welding, occupational and personal risk factors makes attribution of risk to a specific aspect of the exposure a difficult task. For example, exposure to asbestos (an occupational risk factor) and cigarette smoking (a personal risk factor) are both associated with increased lung cancer risk. In the context of combined exposures, the question then becomes one of potential additional risk associated with welding processes, not the risk of the welding process itself.

One way to categorize the health aspects of welding-related exposures is to assess their status in the risk assessment process. The risk assessment process has four stages: (1) hazard identification, (2) establishment of dose-effect relationships, (3) exposure assessment, and (4) risk assessment based on the information from stages 1–3. Most of the information gathered for this review is related to the hazard identification stage of the risk assessment process with some information about different exposure levels involved.

Some aspects of welding have known hazards such as the effects of welding processes on the eye. In addition to the known hazards, there is a large set of unresolved hazards associated with welding. Unresolved hazards have some data to indicate possible hazard but not enough to clearly demonstrate hazard. Cancer, immune system effects, and reproductive effects are all in the unresolved category. There are several reasons why hazards remain unresolved: (1) the relevant aspect of exposure may not be identified correctly and so the effect is diluted by the miscategorized exposures, (2) confounding variables related to occupational and personal risk factors can obscure the relationships under study and preclude the identification of hazards, and (3) the statistical power of the studies conducted may be too low to detect an important health effect or so high as to flag a welding-related trivial biological change as "statistically significant". Potential hazards would be those factors for which there is insufficient information to categorize as either unresolved hazards or as nonhazards. The potential effects of exposure to magnetic fields are in this category.

Unresolved hazards are the most troublesome for risk assessment. It is possible, as outlined below, that no practically attainable study will be able to resolve status of a potential risk factor with respect to welding per se. It may be most effective for risk managers to focus on industrial hygiene and exposure assessment while unique risk factors associated with welding are investigated.

Three reasons why practically attainable studies, especially epidemiology may not resolve unresolved hazards are (1) dilution by miscategorization, (2) confounding variables (other risk factors), and (3) insufficient statistical power. Dilution by miscategorization of exposure is a possibility in any epidemiology study of welding which uses a surrogate measure of exposure. Because the composition of welding fumes is a complex function of the welding process, the process parameters, the material being welded, and its surface coating, dilution by miscategorization will be a frequent aspect of studies which do not include working life-time personal dosimetry which is impractical. The effect of dilution by misclassification is to reduce the magnitude of any effects observed. Occupational and personal risk factors may obscure the identification of health hazards.

Asbestos exposure and cigarette smoking are examples of occupational and personal factors which make the obscure the relationship between lung cancer and welding by increasing the baseline risk. Asbestos and cigarette smoking would be confounding variables if they were correlated with the welding dosimetry measure. An example would be comparing outdoor welders with a control group consisting of indoor workers in a non-smoking office. Statistical power is a measurement of the resolving power of a statistical test which increases with sample size. This means that a small study can only detect large differences and, conversely, that a large study may detect trivial differences. This means that a small sample size has a high probability of failing to detect a genuine, but small, effect. A very large sample size may detect differences so small they fall within the normal range of physiological variation. Statistical detection of a small difference might be of no significance if detected between groups in a cross-sectional experimental design and extremely important if detected in a study where each subject served as their own control.

The process may be expected to continue indefinitely. Potential hazards will be identified and become unresolved hazards. Unresolved hazards will either become known hazards, non-hazards or remain unresolved. This monograph is another step in the resolution process.

Effects of Welding on Health VIII

1. Fumes

Welding fumes can, depending on many factors, including the metals in welding consumables or the material being welded, the welding electrical parameters, the consumable coating or flux core, the shielding gases, coatings or contaminants, or decomposition products (Ref. 177) contain materials which are known or suspected to have adverse health effects under certain circumstances.

The most important reason for understanding these factors is for the management of human risk from occupational exposure. Health effect concerns have been associated with welding from its earliest days (Ref. 97). Fume contents and control are an important aspect of good practice in welding and cutting (Ref. 145).

The large number of factors modifying welding fumes has led to differences in regulatory requirements (Ref. 177). The approach of Scandinavian countries involves classification of electrodes by type of fume and emission rate. German consumables have warning labels if there is more than a 5% concentration of chromium, nickel, or cobalt. In contrast, "The UK view is that there are so many variables in a practical welding environment, that only analysis of fume sampled from the welder's breathing zone provides reliable data" (Ref. 177, p. 504).

Developed countries have various exposure limits for the concentrations of many industrial chemicals including those found in welding fumes, so the issue has now also become one of regulatory compliance as well as industrial hygiene. A variety of methods, instruments, and systems are available for measurement of welding fumes components (Refs. 55, 86, 103, and 104).

Not surprisingly, welding turns up as a priority exposure issue in general industrial hygiene surveys, for example, (Ref. 55) which is a survey of a U.S. army medical center in Germany. Welding/brazing is included in a table of "key hazardous operations" (Ref. 55, p. 186).

There are two general approaches to dealing with welding fumes, personal protection, and engineering controls such as ventilation or source extraction, or both. There are a variety of trade-offs in terms of costs, human factors, and compliance which are involved (Ref. 12 and Ref. 70). Specialized situations, such as hyperbaric welding in underwater environments (Ref. 17) may require additional controls such as chemical and particulate absorbers and catalytic converters.

1.1 Effects of Electrode Composition. Investigation of fume production and chemical composition is an active area in welding research and development. Ideally, the welding process would emit no fumes. If the goal of no fume cannot be attained, then the next best situation would be for the fume to contain no biologically active material. If inertness cannot be attained, then it is desirable to have the minimum biological activity in the fume.

Hexavalent chromium Cr(VI) has been implicated as a carcinogen and is normally present in fumes when welding stainless steel. Griffiths and Stevenson (Ref. 58) indicate that the sodium and potassium compounds in the electrode coatings are associated with the release of Cr(VI) when welding stainless steel. They describe the development of electrodes for the welding of stainless steel which use a lithium silicate binder and have lower levels of Cr(VI) concentrations in welding fumes from 4.9% in 316L regular 3.25 mm electrodes to 0.5% in the experimental Low Fume 316L 3.25 mm electrodes. The electrodes are acceptable for use and in production.

Laser cutting systems can generate aerosol by-products, including metals. The materials released are a function of the material being cut (Ref. 16) so galvanized steel released iron and zinc while 347 stainless steel released chromium iron manganese, nickel, and selenium.

Henderson et al. (Ref. 64) describe the results of an Australian research program involving tests of 36 gas-shielded and open-arc hardfacing and surfacing wires. Fumes were collected with an electrostatic collector. Fume generation rates were expressed as grams of particulate per arc hour and as grams per kilogram of electrode consumed. With the system operating in the midpoint of the voltage/current conditions recommended by the wire manufacturer. With this single load point testing, there was nearly a five-fold variation in grams per hour of generated particulate (100–480) for steel wires and about the same range (60–410) for iron and tungsten composites.

The ratio of chromium in the fume to the chromium in the weld deposit (the fume conversion factor) averaged about 60% with a range from 25 to 88%. The proportion of the chromium that was in the form of Cr(VI) was variable from 4 to 9% for austenitic stainless steel (13XX) wires. The authors indicate that a stainless steel manual metal arc welding would be expected to have 90 to 100% of chromium in the form of Cr(VI).

Nickel concentration in fume samples was 1.8–3.6% by weight for a conversion rate of about 28% for the austenitic stainless steel wire (13XX). The austenitic manganese steel wires (12XX) had lower nickel levels in the deposits and a higher conversion factor of about 70%.

Manganese content in the fume had conversion rate from 190 to 560%.

The authors conclude that there are measurable differences in the consumables but that single load point testing may not give a complete picture of the fume generation.

Olah (Ref. 126) studied six types of high-alloy electrodes intended for manual metal arc welding in nuclear plants. The total chromium content of the fumes by weight ranged from 3 to 8% with Cr(VI) at 2 to 5%. Nickel content was from 0.4 to 5%. The weight of particles emitted per time unit was an increasing function of the welding current. The composition of the fumes from a E-B 847 electrode was shown as function of the welding current from 80 to 180 amps. Across this range, the percentage by weight of iron increased from 12 to 17%, chromium increased from 5 to 7%, and nickel from 3 to 6%. Manganese decreased from 12 to 9%.

Barium exposure was of interest to Zschiesche et al. (Ref. 192). They studied a group of eight welders using stick electrodes containing barium by measuring urinary barium per gram of creatinine and showed that (1) post shift concentrations were higher than prework levels, and (2) the urinary levels were higher on during the week and fell to low levels on the weekend. The use of local exhaust extraction was shown to influence the maximum workplace concentration of barium.

Workplace fume concentrations relative to different shop conditions with metal active gas welding were studied by Eichorn (Ref. 45). Many of the conditions exceeded the maximum workplace concentration, and the emphasis is on ventilation and work practices to keep the fume levels within acceptable limits.

Welz (Ref. 179) compared the rate of ozone production from metal active gas welding with continuous and pulsed current flow. Across a range of wire feed rates and two argon/carbon dioxide shielding gas proportions, ozone production was higher with the pulsed current flow. The reference condition was continuous current flow and argon with 18% CO_2, using only CO_2 and no argon had about 1/3 the ozone levels as the reference. Argon plus 8% O_2 was about 20% above the reference. Pulsed current with either argon and 18% CO_2 or 8% O_2 were about double the reference concentrations. Even the increased ozone production was below the German maximum workplace concentration standard.

Ussing (Ref. 173) produced a large report for the Danish welding institute investigating welding with flux cored wires relative to TIG, MMA, and pulsed MIG welding. The primary emphasis is on weld quality, corrosion, and economics; however, there is an appendix comparing the methods and test conditions for total fume production, and gas emissions of ozone, carbon monoxide, and oxides of nitrogen. With respect to fume emissions, the flux coated wire conditions ranged from 5 to 14 mg/s. Pulsed MIG had about 1 mg/s, manual metal arc about 6 mg/s. Metal inert gas (TIG) was lowest with < 0.1 mg/s. For ozone emission, the flux coated wire tests had the highest concentrations at about 7 ml/minute.

In this test, unlike that reported by Welz (Ref. 179), the pulsed condition had lower ozone emission of about 2 ml/min. There are differences in the gas compositions used between the two reports which merely indicated that detailed process information is required to predict exposure. Manual metal arc welding showed 0 ml/min ozone generation and metal inert gas welding had an ozone emission rate of about 0.5 ml/min. Emission of NOx was highest with a 97% argon 3% CO_2 condition at 6 ml/min. The pulsed MIG and manual metal arc conditions emitted about 4–5 ml/min. Emission of carbon monoxide was highest for the flux coated wire test with levels of 30–60 ml/min. The pulsed MIG, manual metal arc and TIG conditions were less than 5 ml/min.

An index which combined the various parameters showed that overall, the pulsed MIG and the TIG conditions were the lowest in overall hazardous emissions. (Refs. 44 and 173).

1.2 Lead. Larson et al. (Ref. 86) collected fume samples from filters mounted on the outside front of a welder's helmet during gas metal arc welding on carbon steel samples (A-36, 1018, 1010, 1008) using ER70S-3 electrodes. The lead concentrations found, (approximately 5 ug/m^3) were about 10% of the OSHA PEL of 50 ug/m^3. This study is consistent with the hypothesis that the base metal may not be a major source of lead in welding fumes.

1.3 Aluminum. Leonard and Gerber reviewed the toxicology of aluminum and its salts with respect to carcinogenicity, mutagenicity, and teratogenicity and conclude that it is not a hazard "except, perhaps, in cases of extremely high exposure" (Ref. 89, p. 247).

1.4 Aerosol Analysis

1.4.1 Visualization. Visualization is often a key step in understanding. Farrants et al. (Ref. 50) used an array of electron microscope grids mounted on a polycarbonate filter in a standard holder with a 2 l/min sampling pump to obtain samples from the breathing zone of one welder using metal inert gas welding and another using manual metal arc welding on Inconel 62ᶠ ˙ ˜se material. Transmission electron microscopy at magr :cations from 500 to 30,000 times. The particles were classified as small, found in aggregations of 5–10 um in diameter, medium (0.07 um), and large 0.15 um. The medium and large particles were relatively homogene.ous, but the small particles showed evidence of a substructure. There were many agglomerations of the different particle sizes.

There was a difference in the distribution of the three particle sizes between metal inert gas and manual metal arc welding. In manual metal arc welding, the three sizes were approximately equally represented. In the metal inert gas, large particles predominated (47%) and the proportion of medium particles was reduced (24%). Differences in the particle sizes would influence the distribution of deposition in the respiratory tract and modulate any toxicity observed.

1.4.2 Photoelectron Spectroscopy. Voitkevich (Ref. 175) used x-ray photoelectron spectroscopy to etch through welding aerosols and identify the composition at different depths in the particle. With cellulose-covered electrode TsM-7, for example, over an etching depth of 50 nm, the concentration is little changed for oxygen, increases for manganese and iron, and decreases for silicon, potassium, and sodium. From the spectra, the surface layer is mainly oxide compounds of potassium, silicon, and sodium and the interior is Fe_3O_4 and $MnFe_2O_4$. In fume from flux-cored wire PP-AN8, the silicon concentration declines from the surface to about 5 nm and then is constant, iron, manganese, and oxygen all increase with depth, and fluorine, sodium, and potassium decrease.

1.4.3 Particle Growth. Growth of particles and agglomeration is a function of the temperature, humidity, and deposition. Rudell et al. (Ref. 143) studied particle growth from welding on mild steel by manual metal arc and metal inert gas welding. The aerosol was generated in a 0.5 m^3 Plexiglass box. Cascade impactors were used to collect samples at ambient temperature and from body temperature (37.1 degrees C) and 99% relative humidity. The mass median aerodynamic diameters of all processes for potassium, calcium, manganese, and iron were all 10–50% larger in the simulated lung. The implication of this is that aerosol size increases as it enters the simulated respiratory tract. This, in turn, means that particles might impact and deposit earlier in the airway than one would expect from the external particle size distribution.

Rudell et al. (Ref. 143) also had humans inhale a welding aerosol from the manual metal arc process through the nose and exhale through the mouth into a sampler. The exhalation sampler was heated to body temperature. The mean exhaled particle size for the elements was as large or larger than the inhaled particles, indicating some growth took place. The percentage of deposition was highest for potassium 67–80% and 48–70% for the others.

1.4.4 Optical Methods. In contrast to the impactor methods for measuring aerosol size, Niessner et al. (Ref. 112) describe a four wavelength simultaneous photoelectric aerosol sensor. Charged particles are stripped from the particle sample stream which is split into four substreams each irradiated with ultraviolet light to charge the particles before detection by aerosol electrometers operating at 185, 214, 229, and 254 nm. A variety of monodisperse aerosols and test mixtures were used to evaluate the operation of the system. By using statistical principal components analysis it was possible to develop classification rules which attained 77% correct classifications of particle identity. This system has the potential for development into a virtually real-time analyzer which might be applicable to industrial hygiene studies of welding fumes.

Pal and Gyorgy (Ref. 130) took an optical approach to the problem of measuring particle size and concentration of aerosol samples. They used an optical path through a sample tube and measured extinction values (intensity at which the signal could just not be detected) at three wavelengths of light. They used welding fume aerosols in measures repeatability of the ratios of the various extinction values. This approach is not as well developed as that described by Niessner et al. (Ref. 112) although the same type of statistical approaches could be applied. Although welding fumes were used in the testing, this is a long way from a practical field instrument for industrial hygiene.

1.4.5 Atomic Absorption Analysis. If Cr(VI) is the relevant fume component for assessment of carcinogenic potential, then improved methods for measuring Cr(VI) should be useful. Brescianini et al. (Ref. 20) studied interferences with electrothermal atomic absorption spectrophotometric determination of Cr(VI). Interference from iron, potassium, sodium, and calcium were demonstrated when the Cr was in low concentrations relative to the interfering chemical. Their approach to interference minimization is to use an Amberlite La-2 ion-exchange resin. After extraction of samples and standard, the extracted samples and standards are analyzed in the atomic-absorption furnace. Analysis with and without extraction of replicates of four fume samples from the Danish Welding Institute showed good repeat reliability and that the Cr(VI) measurements without extraction for manual metal arc welding of stainless steel may overestimate Cr(VI) by about 30%. Welding of mild steel either by manual metal arc or metal inert gas showed levels of about 0.5 ug without extraction and 0 ug with extraction. Metal inert gas welding fumes from stainless steel were overestimated by about 10% without extraction.

1.4.6 X-Ray Florescence Spectrometry. An alternative approach to speciation of Cr is the use of high-resolution x-ray florescence spectrometry. After conversion from scanning angle to energy and normalizing over intensity, the spectra are plots of relative intensity of florescent emission versus beam energy. The peak location and shape are determined by the chemical species present. For the peak resolution method, spectra from the reference samples were used to calculate synthetic profiles for mixtures in different concentrations. Reference samples were Cr(III), Cr(VI), and metallic Cr powder. Fume samples from welding stainless steel SUS 304 with a rod corresponding to AWS E308-16 were compressed into a disk. Two methods were tried for x-ray florescence analysis of the samples, peak position measurement and a peak resolution method, and were compared with a wet chemistry method. The peak resolution method had slightly closer agreement with the wet chemistry method than the peak position approach.

1.5 Ozone and Nitrogen Oxides. Ozone is generated in welding processes by exposure of oxygen to ultraviolet light. Ozone is unstable in air, and its decomposition is enhanced by metal oxide fumes. Processes such as SMAW and FCAW which generate large quantities of fumes are not associated with significant quantities of ozone (Refs. 94 and 131). An engineering approach to the reduction of ozone and nitrogen dioxide emissions from GTAW is to add nitric oxide to the shielding gas. Appelberg (Ref. 10) describes Mison as a patented shielding gas, developed following published concerns from Swedish Trade Unions, which can be used in place of argon in GTAW. Containing less that 0.03% nitric oxide, Mison is claimed to reduce total emissions of ozone and nitrogen dioxide by 30 to 90%.

1.6 Carbon Monoxide. Tsuchihana and co-workers investigated the carbon monoxide (CO) exposure and carboxyhemoglobin levels of welding workers using CO_2-arc welding. Working conditions were categorized as indoor and outdoor and workers were categorized as smokers or non-smokers. Concentrations of CO in air, apparently near the plume were over eight times higher for inside welding at up to 800 ppm. Concentrations measured with personal samplers are shown in Table 1{seq table carbmonox} adapted from Table 1 (Ref. 169, p. 280).

As a point of reference, the Biological Exposure Index for CO measured as carboxyhemoglobin in blood at

Table 1
Carbon Monoxide Exposure Levels by Work Location and Time of Day and Smoking Status

	Inside Work		Outside Work	
Period	Nonsmoker	Smoker	Nonsmoker	Smoker
Morning	28 ± 13	17 ± 7	5 ± 3	6 ± 4
Afternoon	19 ± 10	17 ± 6	3 ± 3	8 ± 3
Total (8 h)	24 ± 11	16 ± 2	4 ± 3	6 ± 3

Table units are mean ppm ± standard deviation.
Data from (Ref. 169, p. 280)

the end of shift is stated as, "less than 8% of hemoglobin" with the notations B and Ns indicating that there is a background level of carboxyhemoglobin and that it is a nonspecific measure of exposure (Ref. 5).

Individual levels of carboxyhemoglobin in welding workers performing inside work shown in Figure 1 of Tsuchihana et al. (Ref. 169) exceeded 15% COHG. This is approaching the level of COHG (20%) which increases the vascular wall permeability to macromolecules which may be important in the pathogenesis of atherosclerosis (Ref. 60), p. 453 but below the 30% level associated with electrocardiogram changes, headache, weakness, nausea, or dizziness (Ref. 155, p. 268).

2. Electromagnetic Radiation

2.1 Light. Exposure measurement is an important aspect of the industrial hygiene of welding. The welding process involves heating materials to high temperatures, and materials emit radiation as a function of temperature (Ref. 79). Measurements of the light emitted by welding processes in the infrared, blue, and ultraviolet wavelengths is of relevance to safety. Instruments are being developed to characterize the emissions from welding processes and, potentially, lead to the development of personal light dosimeters.

Okuno (Ref. 125) had developed an instrument to measure infrared radiation in the work location. One of the applications cited is the potential to improve the sensitivity of epidemiologic investigations. Measurement of infrared radiation 50 cm from the arc on mild steel was 7.25 mW/cm^2 for the shielded metal arc method and 1.71 mW/cm^2 for metal active gas shield arc method. Similarly, Okuno (Ref. 124) had reported the development of an instrument to measure blue light radiation (400–500 nm wavelengths). As an example of the use of the instrument, the blue light radiation levels from shielded metal arc welding of mild steel (10.5 W/cm^2sr) and the

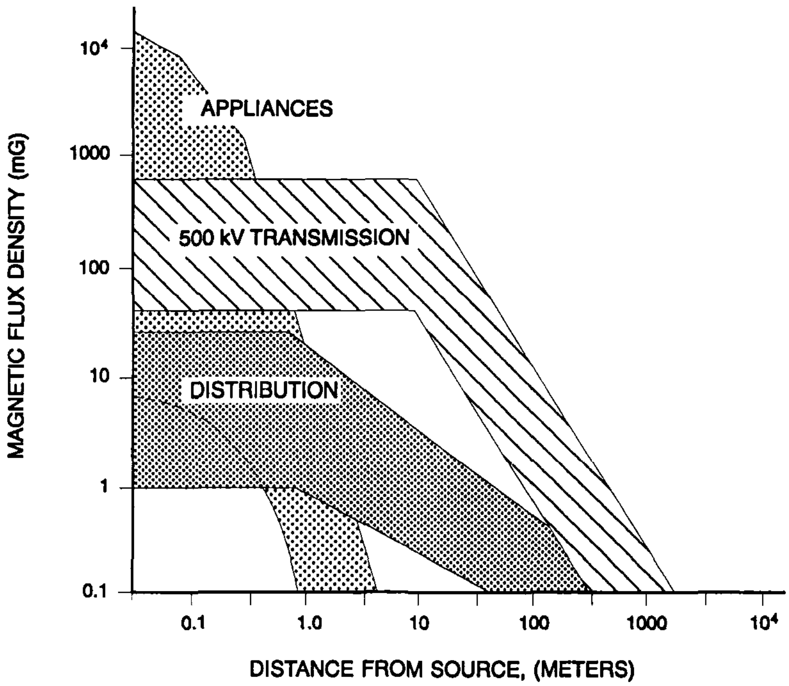


ILLUSTRATION OF HOW THE MAGNETIC FIELD INTENSITY AT GROUND LEVEL CHANGES WITH HORIZONTAL DISTANCE FROM THREE COMMON SOURCES OF POWER-FREQUENCY MAGNETIC FIELDS. THE BANDS REPRESENT VARIATION ACROSS INDIVIDUAL SOURCES IN EACH GROUP. ADAPTED FROM (FLONG 87a).

Figure 1 — Electric and Magnetic Exposure from Transmission Lines (Ref. 172)

sun at about noon were measured, and the ACGIH permissible exposure durations were calculated as 9.5 and 1.6 seconds respectively.

Measurement of the ultraviolet radiation in the field situation apparently has problems with temporal fluctuation and reproducibility. Mariutti and Matzeu (Ref. 99) performed laboratory measurements using gas tungsten arc welding of stainless steel. An actinic radiometer was used to measure the overall intensity of the arc and a spectroradiometer was used to measure the spectral irradiance from which the effective irradiance can be computed. In other words, variations in arc intensity due to arc length, fume shielding, etc. were compensated for by using the overall level with the actinic radiometer to normalize the readings during the two hour period of time required to make measurements at 1-nm intervals between 250 and 400 nm with each irradiance measurement integrated over 10 seconds. By using the spectroradiometer in its scanning mode, it was possible to obtain a normalized spectrum in approximately three minutes which is more practical for field observations. The authors conclude with the assertion that they have used the system in several workplaces for exposure evaluation.

Lasers are being applied more frequently in welding applications and have some important differences from electric arc processes. Rockwell and Moss (Ref. 140) review optical radiation hazards from CO_2 lasers in welding applications. The CO_2 laser operates at a wavelength of 10.6 um (infrared). Typical systems have continuous wave radiant power outputs between 100 W and 10 kW. Reflection of the beam from high-powered CO_2 lasers (> 10 kW) from the work surface can cause diffuse reflection hazards in the vicinity (< 2 m) of the target (Ref. 140, p. 419). The absorption of radiant energy by the target is influenced by surface plasma formation. The best coupling occurs in a metal specific intensity ranging from about 105–107 W/cm², and less energy is reflected. Shielding gases may influence the radiation scattering from the target. Engineering controls and detailed analysis are necessary to define the regions where potentially hazardous exposure has a high probability — the nominal hazard zone (NHZ). The size of the NHZ depends on the configuration, target, and power level of the laser in question. For a 1 second exposure with a 500 W CO_2 laser, the intrabeam hazard zone extends for 160 m (Ref. 140, p. 422). A separation of 2 m from a diffuse reflection will "provide adequate safety for laser powers up to 12.5 kW" (Ref. 140, p. 422).

2.2 Extremely Low-Frequency Electromagnetic Energy (ELF). Articles in the popular press (Ref. 26) and scientific journals reflect concerns about potential health effects of low-frequency electric and magnetic fields (Ref. 193, Ref. 68, and Ref. 8) and high-frequency electromagnetic exposure (Ref. 8 and Ref. 82). Low-frequency electromagnetic field exposure is relevant to electric arc welding processes and induction heaters for metal-glass welding in the vacuum tube and laser industries. High-frequency exposure is relevant to electron beam processes and plastic welding.

The health effects, if any, of exposure to these fields are not well defined, although concerns include cancer, reproductive hazards, and effects on the central nervous system. Walborg has reviewed the scientific literature on extremely low-frequency fields on aspects of cancer and has summarized the available studies (Ref. 176). In his summary, Walborg's concluding statement is, "Present scientific evidence is insufficient to support the contention that exposure to power frequency electromagnetic fields contributes to an increased cancer risk, and any consideration to institute regulations regarding human exposure would be premature." (Ref. 176, p. 102).

Hrnjak and Radojkovic (Ref. 68, p. 67) reviewed the available information about electric field exposure and concluded that, "It is considered that exposure to electric fields up to 20 kV/m does not constitute a danger to health and that there is no need to limit exposure to field below 10 kV/m." Alternatively, other authors have observed that "not proven" is not the same as "not guilty" with respect to potential health risks and recommend further research (Ref. 172). Morgan recommends that, "If individuals and society are concerned about the possible risks from fields, they can take prudent steps to avoid exposure to fields, while avoiding large unjustified expenditures" (Ref. 106, p. 39). Morgan defines prudent avoidance as, ". . . limiting exposures which can be avoided with small investments of money and effort" (Ref. 106, p. 24).

In order to put the field exposure levels for welding into perspective, Figure 1{seq figure powerlines} (Ref. 172, p. 13) shows a range of measured magnetic field exposure levels associated with electric power transmission, distribution, and appliances as a function of distance from the source. Most of the epidemiology studies which have raised concerns about cancer have been concerned with residential exposures less than 10 mG.

Some exposure assessment of fields associated with welding has been conducted (Ref. 193, Ref. 161, and Ref. 95), the most useful of which is by Stuchly and Lecuyer. Table 3 is an adaptation of Table 2 from Stuchly and Lecuyer (Ref. 161). To convert from the uT units to mG, one multiplies by a factor of 10. From inspection of the table, it is apparent that localized exposures larger than 1000 mG were common in the situation studied by these authors. These levels are below current U.S. consensus guidelines for occupation magnetic field exposure for which the TLV at 60 Hz is 1 mT which corresponds to 10 G (Ref. 4). Stuchly and Lecuyer (Ref. 161) measured electric and magnetic fields at the power frequency of 60 Hz and low harmonics near 22 arc welders. Electric fields were typically very low, about 1 V/m. Magnetic flux densities ranged from less than 10 uT to a few hundred uT. Several devices had exposures in the range of 200–400 uT. These levels are of a level encountered in special occupational settings.

It is conceivable that electric currents in the body could interact with dental amalgams to produce increased levels of copper and mercury exposure. Divers in wet suits performing underwater electric welding or cutting are in the path for stray currents to ground. Ortendahl et al. (Ref. 127, p. 559) conducted a pilot study with five divers. Based on the literature review in their introduction they assert: "The problems, consisting of a metallic taste and/or degradation of dental amalgam restorations, have been strictly related to electrical welding/cutting under water." The normal fluctuations in background levels of mercury and copper from dietary consumption, intra-individual differences, and limitations in the number of subjects and analytical sensitivity keep their report from being conclusive. Graphs of individual subjects as a function of time before and after exposure suggest that some of the subjects had increased mercury in whole blood, copper (adjusted to creatinine) in urine, and plasma copper levels. There may be an uncontrolled variable present which accounts for the different apparent populations of responders and nonresponders.

Table 2
Blood Carboxyhemoglobin Levels by Location of Work, Time of Day, and Smoking Status

	Inside Work		Outside Work	
Period	Nonsmoker	Smoker	Nonsmoker	Smoker
Morning				
Before work	1.8 ± 0.8	5.4 ± 1.9	1.3 ± 0.2	5.9 ± 2.2
After work	8.8 ± 4.7	7.2 ± 4.3	1.5 ± 0.4	4.6 ± 1.3
Afternoon				
Before work	6.6 ± 3.5	6.5 ± 3.9	1.4 ± 0.3	6.1 ± 2.4
Break 3 p.m.	7.5 ± 3.3	7.0 ± 3.9	1.7 ± 0.6	4.7 ± 1.8
After work	8.3 ± 5.4	9.2 ± 5.3	1.4 ± 0.5	4.5 ± 1.9

Table units are mean % COHg ± standard deviation.

Table 3
Operator Exposure to Magnetic Field (Rms Values at the Frequency of the Strongest Field)

Model	Current A	Head μT	Chest μT	Waist μT	Gonads μT	Hand μT	Legμ T
Airco AC/DC Heliwelder	300	0.4	5	9	21	9	5
Canox AC Arc Welder	100	56	82	—	151	63	119
Canox AC Arc Welder	140	119	264	—	289	113	—
Canox Arc Welder	130	2	2	1	2	4	—
Canox Mig Welder	300	—	—	6	—	—	—
Canox Mig Welder	450	7	10	19	25	23	—
Canox Spot Welder Portable	36	75	188	440	628	1005	251
Canox Spot Welder	575	75	88	188	126	—	—
Canox Arc Welder	125	94	113	440	440	377	188
Canox Arc Welder	90	25	88	126	126	126	113
Elektra-Beckum Mig Welder	20	6	7	7	7	9	—
Hobart H.F. Tig Welder	120	201	226	—	138	151	138
Hobart H.F. Tig Welder	50	94	138	—	151	75	126
Lincoln Tig Arc Welder	375	100	126	314	314	314	314
Lincoln Tig Arc Welder	—	75	15	38	75	126	50
Linde (Union Carbide) Welder	240	75	82	151	364	—	377
Linde (Union Carbide) Welder	185	50	126	251	188	—	126
Liquid Carbonic Stick Welder	180	50	113	251	226	151	—
Miller (Canox) Bancroft Welder	500	200	88	126	100	—	56
Miller Inert Tig AC/DC Gas Welder	320	16	50	—	75	126	—
Miller Portable Spot Welder	15	—	—	0.5	—	—	—
Thermal Dynamics Cutting System	400	4	4	6	8	8	10

Adapted from (Ref. 161)

2.3 Radio Frequency Electromagnetic Energy. Induction heater operating at frequencies between 300 kHz and 790 kHz were surveyed by Andreuccettii et al. (Ref. 8). Electric field strengths of up to 8 kV/m were observed as were magnetic fields up to 20 A/m. These systems are used for several technical processes including glass-metal welding in the construction of electronic vacuum tubes and the welding of relay contacts in a bell jar containing a reducing atmosphere. Three of ten systems studied had electric fields above the 1982 ANSI C95.4 exposure guideline for the hands and four systems were above the electric field guideline in the head region. Magnetic fields exceeded the guidelines for two or more of the head, hands, or abdomen in six of the systems studied.

Plastic welding can involve radio frequency radiation. Hedman et al. (Ref. 82) studied 115 men and women with structured interviews with rating of subjective symptoms and tests of coordination and 2-point discrimination. Referents consisted of 23 sewing-machine and assembly operators. The units are not described in detail, although the article states that the operating frequencies were measured. The measured power density levels exceed 100 W/m^2 on 62% of the measurements and 250 W/m^2 (the Swedish ceiling value at the time) on 50% of the observations.

Radio frequency burns (deep and slow healing) were reported by 70% of the women and 60% of the men to occur at least once per year. Irritation of the eyes was reported by 23% of the men and 40% of the women. The author states that paresthia was more frequent in the radio frequency energy exposed, but they do not provide the figure. Adverse pregnancy outcomes were within the normal range relative to the general Swedish population.

The relatively high levels of exposure to magnetic fields associated with some welding processes may lead to the conduct of epidemiologic studies of electric welding workers including magnetic field dosimetry. It is also possible that studies of other exposed occupational groups may cause reassessment of TLV levels or the development of other guidelines for magnetic field exposure. If the concept of prudent avoidance becomes widely accepted, there may be pressure on the welding industry to reduce the levels of magnetic field to which workers are exposed.

2.4 Ionizing Radiation

2.4.1 Weld Inspection Accidental Exposure. Radiographic inspection of weld joints leads to the potential for unintentional exposure to ionizing radiation. Jalil and Molla (Ref. 72) describe an incident involving an unskilled local laborer employed as an untrained radiographer on a project in Bengladesh. The 192Ir source pellet became detached from its coupling and did not return to its safe storage position after the first exposure in a series. The worker stated he had mild vomiting and diarrhea shortly after the incident. Within seven days severe inflammation and pain was associated with redness, swelling and tenderness of the palmar surfaces and tips of thumbs, index, and middle fingers. Abscess developed on the fingertips and the fingernails fell off. The health condition of the victim was described as, "deteriorating continuously" (Ref. 72, p. 118) during the 1.5 years since the accident.

2.4.2 Exposure Minimization Through Underwater Welding. In contrast to the previous report where the operator was unaware of radiation exposure, other circumstances involved known exposure to ionizing radiation and specialized procedures are used to minimize exposure. In particular, water can serve as a radiation shield to minimize personnel exposure.

Repair of a crack in a steam dryer in a boiling water nuclear reactor described by O'Sullivan (Ref. 128) involved several steps designed to meet an ALARA (As Low As Reasonably Achievable) personnel exposure policy for the repair. Underwater SMAW was the approach selected. Following procedure and welder qualifications at a depth of 3 m underwater, several steps were taken to minimize exposure during the repairs. Complete dry suits and pressure tested before each dive, were used to avoid contact with radioactivity contaminated water in the equipment pool. A thermo-luminescent and two self-reading dosimeters were taped on the diver on each ankle, thigh, forearm and upper arm, the groin, chest, back and top of the head for a total of 12 locations and 36 dosimeters. Health physics technicians monitored a remote-reading dosimeter taped to the area of highest expected exposure and could communicate with the diver to suggest position changes to minimize exposure. Support for the diver/welders included a six person crew of mechanics, three or four health physics staff members, and two video equipment operators.

The total exposure of the 10 divers was 6.7 man-rem for the repairs using wet welding. The author estimates that manual welding in a dry environment would require more than 80 welders and have involved 100–120 man-rem of radiation exposure.

3. Production Coatings

3.1 Organics Released by Heating. Both organic and inorganic chemicals can be released in fumes from welding or oxyfuel gas cutting of painted structural steel. Table 4{seq table organics} shows organic compounds Engstrom et al. (Ref. 48) identified by testing coated steel plates, sampling the plume and identifying the organic compounds by chromatography or spectroscopy.

Apparently some lacquers (Ref. 153) when heated can release isocyanates. In samples obtained: "In a field measurement of air concentrations in welding work on lacquered metal parts at a motorcar workshop" (Ref. 153, p. 453) 1, 6-hexamethylenediisocyanate was found at concentrations above 600 ug/m^3. The article is about the capillary gas chromatographic method and the derivitization steps required to perform the analysis, not the systematic sampling of a welding situation.

3.2 Inorganics Released During Welding or Cutting. Rekus is unequivocal in his warning, "Exposure to lead poses a clear-and-present danger to employees who weld or oxyfuel gas cut painted structural steel." (Ref. 138, p. 25). He points out that lead containing paint is still used as an industrial coating on structural steel. Rekus cites three cases of excessive lead exposure. In case 1, following admission of a crew of lead intoxicated outdoor bridge workers, investigation revealed that most of the breathing zone samples exceeded 750 μg/m^3 which is more than 15 times the level permitted by state occupational health regulations. In case 2, investigation of workers dismantling blast furnace stoves with oxyfuel gas cutters with four foot torches revealed exposures to lead of 10–14 times the PEL. In case 3, workers were

Table 4
Organic Chemicals Released from Oxyfuel Cutting of Painted Structural Steel

Paint Type	Major Compound Identified
Epoxy	Alkylated benezenes Aliphatic alcohols (C_1–C_4) Bisphenol A, Phenol
Ethyl silicate	Aliphatic alcohols (C_1–C_4) butyraldehyde
Polyvinyl butyral	Aliphatic alcohols (C_1–C_4) butyraldehyde, formaldehyde butyric acid
Modified epoxy ester	Aliphatic aldehydes (C_1–C_9) Aliphatic acids (C_5–C_9) methyl methacrylate butyl methacrylate phenol, bisphenol A
Modified alkyd	Aliphatic aldehydes (C_6–C_9) Acrolein Phthalic anhydride Aliphatic acids (C_5–C_9)

Adapted from (Ref. 48)

hospitalized for lead intoxication and investigation revealed lead concentrations in the breathing zone in excess of 20 times the PEL. Rekus recommends (1) engineering controls (long-handled torches and vacuum blasting to remove lead paint before welding or cutting), (2) modified work practices (no cleaning with compressed air and not smoking, eating, or drinking on the job), (3) environmental air sampling, (4) respiratory protection with either a powered air-purifying respirator or an air-supplied regulator, and (5) full-body protective clothing such as coveralls. Rekus cautions about allowing workers to launder their own coveralls at home and cites an example where an employee's home carpet had to be removed and disposed as hazardous waste because of lead contamination.

Working with coatings containing lead can be done safely. Adkison (Ref. 2) describes a project at a utility company where lead coatings were appropriately removed, and good industrial hygiene practices were implemented for safe oxyfuel cutting of floor pieces which had been coated with lead containing paint.

The coating industry has responded to the lead issue by developing lead-free coatings which also meet environmental requirements by releasing only small amounts of volatile organic compounds when they are applied. Whitesell (Ref. 182) describes the new coatings from the perspective of a manufacturer, and it is apparent that the driving force is air quality requirements related to volatile organics emissions during drying.

Coatings without lead are economically beneficial because of the protective procedures required with welding or oxyfuel cutting of structures painted with lead containing paints are considered (Ref. 2 and Ref. 138). However, the long-term implications of the organics released in the plume from various paints (Ref. 48) are not yet understood, and precautions may eventually be required for the organics.

Heinakari et al. describe (Ref. 63) testing which indicates that shop primers with a reduction of zinc silicate concentration from 60–70% to 20–30% can have appropriate welding properties to produce high-quality welds.

4. Hygiene and Work Practices

4.1 Robots. One of the trends in industry, and in welding (Ref. 98 and Ref. 22) is the increasing use of automation, including robots. Robots have the potential to have a positive impact on the health of welders because they have the potential to reduce the exposures (to fumes, radiation, etc.) of human welders (Ref. 110). Robots also have the potential for negative impact on the health of welding and industrial workers because of the possibility of new classes of accidents. Robots are a new element in the welding safety matrix because they exhibit a range of intelligence. Specialized safety requirements for industrial robots (Ref. 62) require consideration of specialized operational conditions, such as "training", mechanical, for example crush hazards, as well as the action of any specialized effectors such as welding equipment.

One trend is in the development of intelligent universal robots. Advances in concepts of multisensor integration and fusion for intelligent systems (Ref. 92) and experimentation with welding systems with fuzzy logic controllers and fuzzy filters (Ref. 147) are leading to systems which will have new potential hazards to workers. As an improbable example, suppose the fuzzy logic controller probabilistically identifies the pattern on someone's shirt as the target for welding. It can be anticipated that problems analogous to those which can occur with poorly trained human operators will be displayed by poorly trained machines. Percival (Ref. 132) has reviewed safety considerations for the use of robots in arc welding and identifies several important issues: (1) legal requirements under health and safety laws, (2) hazard source identification, (3) risk analysis, (4) machine mechanical interlocks, (5) software considerations, and operator/trainer qualifications.

Clews (Ref. 35) has questioned the trend toward universality in robots and argues for specialization for autobody welding applications primarily on the basis of cost. A corollary of increased specialization may, however, be related to safety and health because simpler and "dumber" systems will have a smaller set of fault conditions with the potential for adverse impact on the workers.

4.2 Accidents/Personnel Safety

4.2.1 Published Searches. Literature searches published by the National Technical Information Service cover information related to personnel protection in welding over a span of about 15 years from the early 1970's through 1988 from the NTIS database (Ref. 121) and from the Information Services in Mechanical Engineering Database (Ref. 122). These searches include abstracts and subject term indices. The NTIS database was one of those searched for this health effects review.

4.2.2 Fault Tree Analysis. Welding is included with electrocution, confined spaces, explosions, and power tools in fault tree analysis of 615 fatal work injury events (Ref. 189). The categories were not mutually exclusive. Explosions were indicated in 76% of welding incident reports (Ref. 189). The first branch of the fault tree is "Personnel in Contact" and "Hazards". For welding, the branches from "Hazards" were asphyxia, fire, electrocution, and explosion. Seven additional pages of detail follow the main breakdown.

A more qualitative report about fatalities related to welding and cutting was developed by Cloe at the U.S. Department of Labor (Ref. 36). This report summarizes

217 selected case files available within OSHA with 262 fatalities related to welding over the period 1974–1985. Summaries of 164 case files are included in the report. The welding related fatal incidents are divided into three sections: (1) general industry, (2) construction, and (3) maritime.

Welding related deaths in these areas from 1974 through 1985 are summarized in the reproduction of Table 5 (Ref. 36). Because the data is not normalized to the total amount of welding activity, it is not possible to determine trends in the accident rate from the table.

Tables extracted from (Ref. 36) listing a matrix of type of accident and general contributing factor with frequency are shown for general industry in Tables 6 through 8, for construction in Tables 9 and 10, and for maritime welding in Tables 11 and 12.

4.2.3 Partially Chlorinated Hydrocarbons. 1,1,1-Trichloroethane is cited as an example of a solvent which does not have a reported flash point, presumably because it is difficult to ignite in the standard tests, which "is, in fact, flammable and can form explosive mixtures with air. . ." (Ref. 21, p. 2). Explosions are cited occurring with containers which contain 1,1,1-Trichloroethane vapors. Bretherick points out that dichloromethane, trichlorethylene, and bromomethane are examples of partially halogenated hydrocarbons which will ignite with sufficient ignition energy.

4.2.4 Foam Insulation. Broughton et al. (Ref. 27) describe the evaluation of four arc welders intermittently exposed to off gassing products from an insulating foam over a two day period. When examined, they had flu-like symptoms: nasal congestion, headaches, dizziness, burning eyes, urination difficulties, and sleep problems. Medical records indicated no previous problems, and typical examination values (blood cell counts, clinical chemistry, EKG, x-rays, and spirometry) were normal. Although not clear in the report, it appears that the symptoms persisted over an extended period. Analysis of the polyurethane insulating foam indicated concentrations of isocyanate compounds which can conjugate with serum albumin and function as a hapten to induce an immunologic response. Patient serum was analyzed for antibodies to hexamethylene monoisocyanate-serum albumin and formaldehyde-serum albumin conjugates. Antibody levels (IgG) for HDI-SA were much higher in the exposed welders than non-exposed controls. Response of lymphocytes from the welders to mitogens was mixed. Two patients had the expected blastogenic (immune) response and two had an inappropriate decrease. The authors conclude that the welders' condition was exposure related and reflected in long-term immunologic changes.

Table 5
Number of Fatalities Related to Welding and Cutting by Year of Occurrence

Year	(A) General Industry	(B) Construction	(C) Maritime	Total
1974	3	1	6	10
1975	10	4	8	22
1976	12	10	9	31
1977	6	5	9	20
1978	8	9	5	22
1979	14	16	6	36
1980	18	16	5	39
1981	7	9	2	18
1982	12	0	10	22
1983	13	4	0	17
1984	10	3	1	14
1985	8	3	0	11
Total	121	80	61	262

Adapted from (Ref 36)

4.2.5 Welding As Ignition Hazard. Welding operations can serve as an ignition source local to the point of operation, for example to dusts (Ref. 75) or explosive vapors in containers (Ref. 15). The problem of welding or cutting containers is well appreciated and is the subject of an American Welding Society booklet (Ref. 6). It is also possible for welding operations to provide an ignition source at a point remote from the welding operation through improper grounding (Ref. 113).

4.2.6 NIOSH-HETAB. The Hazard Evaluations and Technical Assistance Branch (HETAB) of NIOSH performs field investigations of workplace health hazards.

4.2.6.1 Cancer Cluster in Pennsylvania. HETAB, in response to a request from OSHA, investigated a suspect cluster of 37 cancer cases in an electrical equipment plant (Ref. 114). Sixteen of the cases were lung cancer. Welding fumes were included along with high-voltage electricity, paint solvent vapor and transformer oils were listed as possible. Past exposures may have included asbestos and polychlorinated biphenyls. The authors conclude that: "It is likely that this increasing number of cancers in recent years is the result of an aging cohort, and not the result of exposure to specific hazards at the plant" (Ref. 114).

4.2.6.2 HETAB Industrial Hygiene Surveys. Two HETAB Health Hazard Evaluation Reports describe extensive field operations in a welding (Ref. 118) shop and in a thermal arc spray facility (Ref. 117). Both surveys contain extensive measurements of air samples for dusts, metals, and solvents. The recommendations from both

Table 6
Welding General Industry Type of Accident by Indicent Type

Type	Operating Procedure	Equipment Material Facility	Environ-mental Condition	Other	Number of Incidents
Fire/explosion in open surrounding from vapors/flammables	20	0	0	1	21
Explosion from cutting into drum/barrel/small container	19	0	0	1	20
Fire/explosion welding/cutting large asphalt/fuel/etc. tanks	19	0	0	0	19
Explosion/fire resulting from welding/cutting pipes to tank	13	0	0	0	13
Burns/injuries from trailer/tank truck explosion/fire	9	0	0	0	9
Electrocution	3	2	1	0	6
Fire/explosion while confined work space	4	1	0	0	5
Caught under or between collapsing material objects	0	4	0	0	4
Explosion/fire from tans/containers used as work supports	4	0	0	0	4
Explosion heating drum/pipe/container to soften/unclog agent	3	0	0	0	3
Caught in, under, or between machinery/equipment/vehicles	3	0	0	0	3
Burned in flash fires	2	0	0	0	2
Struck by flying/swinging objects (other than explosions)	0	2	0	0	2
Struck and/or thrown by explosion/release of pressure	1	0	0	1	2
Heart Attack	0	0	0	2	2
Struck/crushed by falling objects	0	1	0	0	1
Clothing ignited from excess oxygen	1	0	0	0	1
Welding equipment ignited (lack of training)	1	0	0	0	1
Asphyxia/poisoning from hazardous vapors, smoke, etc.	0	0	1	0	1
Unknown cause or source of injury	0	0	0	1	1
Clothing ignited from sparks and molten metal	1	0	0	0	1
Total	103	10	2	6	121

Data from (Ref. 36)

investigations include improved ventilation and enhanced use of respiratory protection equipment.

4.2.6.3 NIOSH Industrial Health Survey. In contrast to the industrial hygiene measurements described above, NIOSH also generates health surveys. A survey of potash mining at six sites (Ref. 119) includes information about potential exposures to hazardous materials. Welding of joining operations (13 types) are included in the report. For each welding or joining operation, the occupational titles, locations, observed and predicted numbers of employees exposed, and percentage of workers exposed.

4.3 Regulations, Guidelines, and Standards

4.3.1 International Regulations. Government regulations, trade organization guidelines, and consensus group standards about welding all have a health effects component. Manz (Ref. 97) has pointed out, there has been concern about the health effects of electric arc emissions since before the turn of the century.

The backdrop of regulations and guidelines is reflected in articles in the welding trade press on eye protection, for example, (Ref. 135) and fume exposure control, for example (Ref. 177) which also includes a sidebar on European Community Directives for the protection of workers.

In the United States, the OSHA Hazard Communication Standard, known informally as right-to-know, requires that hazard information be communicated through material safety data sheets (MSDS), container labels, and training. This is a generic regulation which was expanded in 1988 to cover all employees. Rekus (Ref. 139) has reviewed compliance requirements in the welding arena and laid out a seven step plan to bring an operation into compliance. Woodard (Ref. 187) uses welding products as examples in a tutorial on how to read an MSDS.

Increased regulation with an impact on welding is a world-wide phenomena. Regulations relating basically to exposure minimization were published in 1988–89 in COMECON eastern European countries including the German Democratic Republic (Ref. 90), West Germany (Ref. 81), Britain (Ref. 65), see also (Ref. 57) for a listing of British regulations, (Ref. 171) Canada (cited in 86), and Sweden (87).

Table 7
Welding General Industry Employee Activity by Indicent Type

Type	Operating Procedure	Equipment Material Facility	Environ-mental Condition	Other	Number of Incidents
Not clear	18	0	0	1	19
Welding/cutting on large fuel/water tanks, boilers, etc.	18	1	0	0	19
Welding/cutting drums/barrels containing hazardous materials	17	0	0	0	17
Welding/cutting near flammable material/explosive vapors	11	0	0	1	12
Welding pipes, lines, valves, etc.	10	1	0	0	11
Welding/cutting operations in confined work space	5	1	1	2	9
Welding/cutting on trailer/truck/tanks	7	1	0	0	8
Installing/repairing metal objects/materials	2	1	1	1	5
Attempting to free clogged/frozen pipes/lines/valves	2	1	0	0	3
Welding/cutting steel beams, bulk heads, catwalks, etc.	3	0	0	0	3
Handling material during welding/cutting job	0	3	0	0	3
Using torch to heat, remove substances, etc.	2	0	0	0	2
Lighting/relighting or preparing torch to weld	2	0	0	0	2
Checking/measuring/adjusting or placing equipment/material	1	0	0	0	1
Performing maintenance/adjusting welding machine/equipment	1	0	0	0	1
Moving self/equipment from one area to another on the job	0	1	0	0	1
Using cutting torch to remove part of electrical transformer	1	0	0	0	1
Unknown	1	0	0	0	1
Attempting to escape an area where fire has ensued	1	0	0	0	1
Preparing surface for welding	1	0	0	0	1
Used torch, not his job to do so	0	0	0	1	1
Total	103	10	2	6	121

Data from (Ref. 36)

The regulatory situation is even more complicated when specialized environments with their own safety requirements are combined with welding operations. Schmidt and Szelagowski (Ref. 148) have reviewed the national and international regulations and guidelines for underwater welding operations.

The Canadian Center of Occupational Health and Safety has published a series of technical information sheets on electric (Ref. 32) and gas (Ref. 31) welding and cutting.

In the United States, NIOSH has issued a "criteria document" for a recommended standard covering welding, brazing, and thermal cutting in both summary (Ref. 115) and unabridged editions (Ref. 116). The unabridged version is a 230-page document with extensive process, health, and safety information. The criteria documents are research support input to OSHA for rule-making.

The NIOSH document concludes from the weight of the evidence that: "The main health concerns are increased risks of lung cancer and acute or chronic respiratory disease. Data in this document indicated that welders had 40% increase in developing lung cancer as a result of their work experience" (Ref. 116). They further conclude that: "Excesses in morbidity and mortality among welders exist even when reported exposures are below current OSHA permissible exposure limits for many of the individual components. NIOSH recommends that exposures to all welding emissions be reduced to the lowest feasible concentration using state-of-the-art engineering controls and work practices."

4.3.2 Standards. Standards are promulgated by industry consensus bodies and are intended to reflect current good practice. For example, the American National Standards Institute has published standards related to general safety in welding and cutting (Ref. 1) and on welding and cutting containers which have held hazardous substances (Ref. 13). The British Standards Institution has published standards for power sources, equipment, and accessories for arc welding (Ref. 23) and eye protection (Ref. 24).

4.3.3 Guidelines. In addition to the above two types of publications, national and international welding trade organizations publish safety and health related guidance. The International Institute of Welding (Ref. 129) has published a model fume information sheet for welders and encouraged its translation into local languages. The American Welding Society publishes pamphlets on weld-

Table 8
Welding General Industry Work Location by Incident Type

Type	Operating Procedure	Equipment Material Facility	Environ-mental Condition	Other	Number of Incidents
Establishment, shop, plant floor	16	1	0	2	19
Inside tanks, containers and other confined work spaces	6	2	1	2	11
Repairing/cutting drums/barrels in work area, e.g., garage	10	1	0	0	11
On or near tank trucks	8	0	0	0	8
On drilling rig, in oil field	4	1	0	0	5
Near storage tanks, large containers in work area	5	0	0	0	5
Outside areas, e.g., junkyards, fields, yards, etc.	3	0	0	2	5
Oil refinery locations, e.g., scrubbers	4	0	0	0	4
Roofs of tanks, bins, freezer units, compactors	4	0	0	0	4
Near conveyor belt system, other conveyor	2	1	0	0	3
On or near asphalt tanks	3	0	0	0	3
Near large pipes, lines	1	1	0	0	2
On permanent/semi-permanent platform/catwalk/rack	1	0	1	0	2
Scrap yards or scrapping areas in buildings	2	0	0	0	2
On platform of cherry picker, other mobile platform/cages	2	0	0	0	2
Window of building	1	0	0	0	1
Inside of railroad freight car	1	0	0	0	1
Roofs of buildings, sheds, balconies	1	0	0	0	1
On docks, piers	1	0	0	0	1
Inside transformer	1	0	0	0	1
Near water line and water tank	1	0	0	0	1
Steel foundry floor	1	0	0	0	1
Unknown location	1	0	0	0	1
Inside cargo tank/hold of oil well drilling barge	0	1	0	0	1
Total	79	8	2	6	95

Data from (Ref. 36)

ing and cutting safety (Ref. 129, and Ref. 11) and reprinted the "safe practices" chapter from the Welding Handbook (Ref. 165). The Welding Technology Institute of Australia has published a health and safety manual (Ref. 178). The International Metalworkers Federation has also published a safety manual for welding (Ref. 71).

5. Respiratory Tract

Morgan (Ref. 107, p. 67) reviewed the literature relating exposure to welding fumes and acute or chronic toxicity including pulmonary disease and summarizes that, "The evidence suggests that welding is not a particularly hazardous occupation, provided care is taken to limit exposure to the toxic effects of any fumes that are generated." Morgan is extremely critical of studies involving co-exposure to asbestos, silica, or smoking in combination with welding fumes. Cotes (Ref. 40) argues that the literature base is inadequate and that more extensive research with improved estimates of fume exposure are necessary.

DeWitte et al. (Ref. 43) studied 83 relatively young (approximately 40 years old) welders engaged in shipyard work. Respiratory function parameters were apparently not reduced. A decrease in alveolar diffusion capacity was attributed to cigarette smoking.

Marquart et al. (Ref. 100) studied a small sample of mild steel welders with spirometry across a work week. The 11 welders and 17 controls were monitored for dust and zinc exposure with personal samplers. The study, probably because of the small sample size and low exposure levels, was not able to demonstrate either cross-sectional or longitudinal differences between the groups, except that the welders had higher dust and zinc exposures than exposed nonwelders or controls. In a multiple regression analysis of spirometric parameters, the only independent variable significant at 0.05 or less was age of the subject.

Table 9
Welding Construction Type of Accident by Incident Type

Type	Operating Procedure	Equipment Material Facility	Environ-mental Condition	Other	Number of Incidents
Fall from elevations including through openings	14	4	0	0	18
Fire/explosion welding/cutting large asphalt/fuel/etc. tanks	11	0	0	0	11
Explosion from cutting into drum/barrel/small container	7	0	0	0	7
Fire/explosion in open surroundings from vapors/flammables	4	1	1	1	7
Caught under or between collapsing material/objects	2	2	2	0	6
Struck/crushed by toppling objects, supports cut/weakened	6	0	0	0	6
Electrocution	1	2	1	1	5
Fire/explosion while in confined work space	4	0	0	0	4
Caught in, under, or between machinery/equipment/vehicles	4	0	0	0	4
Asphyxia/poisoning from hazardous vapors, smoke, etc.	3	0	0	0	3
Explosion/fire resulting from welding/cutting pipes to tank	2	0	0	0	2
Struck/crushed by falling objects	1	1	0	0	2
Explosion/fire from tanks, containers used as work supports	1	0	0	0	1
Burns/injuries from trailer/tank truck explosion/fire	1	0	0	0	1
Inside steel cage that fell	0	1	0	0	1
Burned in flash fires	1	0	0	0	1
Fall preceded by electrical shock	0	0	0	1	1
Total	62	11	4	3	80

Table 10
Welding Construction Employee Activity by Incident Type

Type	Operating Procedure	Equipment Material Facility	Environ-mental Condition	Other	Number of Incidents
Installing/repairing metal objects/materials	8	2	0	2	12
Welding/cutting on large fuel/water tanks, boilers, etc.	10	0	0	0	10
Welding/cutting drums/barrels containing hazardous materials	8	0	0	0	8
Welding/cutting steel beams, bulk heads, catwalks, etc.	6	1	1	0	8
Welding/cutting operations in confined work space	5	0	0	0	5
Handling material during welding/cutting job	3	2	0	0	5
Not clear	4	0	0	0	4
Welding/cutting near flammable material/explosive vapors	4	0	0	0	4
Moving self/equipment from one area to another one the job	2	1	0	0	3
Unknown	1	1	0	1	3
Directing/giving instructions to employees	0	1	2	0	3
Welding pipes, lines, valves, etc.	1	1	0	0	2
Lighting/relighting or preparing torch to weld	1	1	0	0	2
Cutting supports from tanks, bins, etc.	2	0	0	0	2
Performing maintenance/adjusting welding machine/equipment	0	1	1	0	2
Welder used sledge hammer to break up concrete	1	0	0	0	1
Checking/measuring/adjusting or placing equipment/material	1	0	0	0	1
Going to/preparing for/cleaning up/leaving work	1	0	0	0	1
Attempting to escape an area where fire had ensured	1	0	0	0	1
Walking/working on unsecured plank or platform	1	0	0	0	1
Attempting to retrieve or remove an article/object, etc.	1	0	0	0	1
Used torch, not his job to do so	1	0	0	0	1
Total	62	11	4	3	80

Data from (Ref. 36)

Table 11
Welding Maritime Type of Accident by Incident Type

Type	Operating Procedure	Equipment Material Facility	Environ-mental Condition	Other	Number of Incidents
Fire/explosion in open surroundings from vapors/flammables	10	3	0	0	13
Fire/explosion while in confined work space	10	0	0	0	10
Explosion/fire in barge/ship compartments (not confined ws)	7	1	0	0	8
Fall from elevations including through openings	5	0	0	0	5
Drowning	4	0	0	1	5
Clothing ignited from excess oxygen	4	0	0	0	4
Fire/explosion welding/cutting large asphalt/fuel/etc. tanks	4	0	0	0	4
Asphyxia/poisoning from hazardous vapors, smoke, etc.	3	0	0	0	3
Electrocution	0	2	0	0	2
Struck by flying/swinging objects (other than explosions)	0	1	1	0	2
Struck and/or thrown by explosion/release of pressure	2	0	0	0	2
Struck/crushed by topping objects, supports cut/weakened	0	0	1	0	1
Burned in flash fires	0	0	1	0	1
Heart attack	0	0	0	1	1
Caught in, under, or between machinery/equipment/vehicles	0	0	0	0	0
Explosion from cutting into drum/barrel/small container	0	0	0	0	0
Explosion/fire from tanks/containers used as work supports	0	0	0	0	0
Struck/crushed by falling objects	0	0	0	0	0
Burns/injuries from trailer/tank truck explosion/fire	0	0	0	0	0
Caught under or between collapsing material/objects	0	0	0	0	0
Unknown cause of source of injury	0	0	0	0	0
Clothing ignited from sparks and molten metal	0	0	0	0	0
Explosion heating drum/pipe/container to soften/unclog agent	0	0	0	0	0
Inside steel cage that fell	0	0	0	0	0
Welding equipment ignited (lack of training)	0	0	0	0	0
Fall preceded by electrical shock	0	0	0	0	0
Explosion/fire resulting from welding/cutting pipes to tank	0	0	0	0	0
Total	49	7	3	2	61

Data from (Ref. 36)

5.1 Alveolar Macrophages. Tissue culture methods were used by Hooftman, Arkesteyn, and Roza (Ref. 67) to study the effects of fumes from welding processes on bovine macrophages. Glass beads (1-4 {SYMBOL 109 \f "Symbol"}m) were used as an inert negative control and the contribution of chromium per se was assessed by using Cr(III) from $CrCL_3$ and Cr(VI) from K_2CrO_4. Fume particulate samples were stored in the dark at –80{SYMBOL 176 \f "Symbol"} C until use. Four types of electrode were sampled for MMA-SS, two for MIG-SS, two for MMA-CI, three for MMA-MS and one for MIG-MS. Cytotoxicity was assessed by obtaining an EC50 (the concentration at which phagocytosis of carbonized latex microspheres was reduced to 50% of control levels) and the LC50 (concentration corresponding to 50% mortality). Based on these indices, the toxicity increased in the order: MIG-MS, MMA-MS, MMA-CI, MIG-SS, and MMA-SS. MIG-MS fumes were similar to the inert glass bead controls. Insoluble Cr(III) was much less toxic than soluble CR(VI) in this assay, When the LC50 and EC50 are expressed in terms of the soluble Cr concentration ({SYMBOL 109 \f "Symbol"}g Cr(VI) ml-1) in the fume samples, the values are similar to the corresponding values for Cr(VI) from K_2CrO_4. The authors conclude that the toxicity of MMA-SS is due mainly to its soluble Cr(VI) and that, based on correlation between toxicity to macrophages and fibrosis, fumes from MMA-SS are potentially fibrogenic.

5.2 Anti-Oxidant Systems. Ceruloplasmin has been reported as a protective molecule against direct oxidant damage to the lung. Pierre et al. (Ref. 133) measured ceruloplasmin in three groups: controls, "confined" welders; and "nonconfined" welders. The welding process is

Table 12
Welding Maritime Employee Activity by Incident Type

Type	Operating Procedure	Equipment Material Facility	Environ-mental Condition	Other	Number of Incidents
Welding/cutting operations in confined work space	8	1	0	0	9
Welding/cutting near flammable material/explosive vapors	9	0	0	0	9
Not clear	4	3	0	0	7
Installing/repairing metal objects/materials	4	2	1	0	7
Welding/cutting operations in ship/barge holds	6	0	0	0	6
Attempting a rescue	3	0	0	0	3
Welding/cutting steel beams, bulk heads, catwalks, etc.	2	0	1	0	3
Welding/cutting near flammable/explosive material on vessels	2	1	0	0	3
Light/relighting or preparing torch to weld	2	0	1	0	3
Moving self/equipment from one area to another on the job	2	0	0	0	2
Unknown	0	0	0	1	1
Returning from break	0	0	0	1	1
Using torch to heat,remove substances, etc.	1	0	0	0	1
Directing/giving instructions to employees	1	0	0	0	1
Welding pipes, lines, valves, etc.	1	0	0	0	1
Performing maintenance/adjusting welding machine/equipment	1	0	0	0	1
Lit cigarette in an oxygen rich atmosphere	1	0	0	0	1
Attempting to put out fire	1	0	0	0	1
Cutting supports from tanks, bins, etc.	1	0	0	0	1
Total	49	7	3	2	61

Data from (Ref. 36)

described as gas-shielded arc welding of aluminum. The "confined" welders were working inside tanks. Blood and urine were collected, and serum ceruloplasmin and copper were measured as was aluminum in urine. The "confined" welders had a reduction ($p < 0.01$) in serum ceruloplasmin but no significant alteration of the copper atoms/ceruloplasmin ratio. The ceruloplasmin level decreased across the work week and recovered over days off work. Serum copper was reduced and the change was not correlated with the biological exposure index of urinary aluminum. Smoking and age were not found (by correlation analysis) to be significant confounding factors. The authors hypothesize that the decline in ceruloplasmin is because it is consumed as part of an extracellular lung antioxidant system which modifies the serum level.

If this hypothesis is correct, it suggests that workers with low ceruloplasmin levels would be a higher risk of oxidative lung damage. It is possible that one day the baseline ceruloplasmin levels will be a screening factor for allowing people to work as aluminum welders.

5.3 Estimation of Retained Particles in Lungs. Methods using tissue samples from different lung regions, for example, the atomic absorption method used by Kraus et al. (Ref. 84) has the benefit of being able to study regional differences and the difficulty that lung tissue is required. Kraus et al. studied lung and hilus tissue of 30 non-exposed and 10 occupationally exposed patients. Vanadium and manganese concentrations were 1.1 to 1.5 times higher in upper lung areas. Two of the patients studied were former "high-grade steel welders" who had 100 times higher manganese concentrations in the lung. Vanadium concentrations were similar in the exposed and non-exposed patients.

The authors point out that manganese exposure in sufficient doses can cause a syndrome similar to Parkinson's Disease.

Smokers had higher median concentrations of manganese and vanadium in 13 of 14 regions measured (seven per lung). The data are not sufficient to interpret a mechanism for this increase. Smokers have reduced pulmonary clearance by the mucocillary system and this may promote the retention of manganese and vanadium.

Noninvasive methods do not require sampling lung tissue and thus have the potential to move from the research arena into the industrial medicine system. Perhaps, one day, noninvasive screening for retained metal particles will be common for welders and as routine as a hearing test. Le Gros et al. (Ref. 88) provide a general review of magnetopneumography, its technology and potential applications.

Two noninvasive methods based on different principles have been reported for measuring the concentration of metals in the thorax. Stern et al. (Ref. 159) described a method for measuring the net thoracic magnetic moment. They used an AC symmetrical susceptibility bridge using pairs of Helmholtz and a fluxgate magnetometer. The system records a signal proportional to the product of the volume and the concentration of ferri- or ferromagnetic material in the sample volume. Water is diamagnetic which makes the net thoracic magnetic moment expected from normal controls negative. Contributions from ferri-, ferro-, or paramagnetic materials make the net moment less negative. The estimated median lung burden was 110 mg Fe_3O_4 which is equivalent to 220 mg of the welding fumes characteristic for the workers studied. Accuracy of the measurement is plus or minus 100 mg.

The authors use respiratory minute volume and presumed concentration level of welding fume to calculate that over a 16 year period, 360 grams of fumes have been inhaled. Citing other researchers' calculations for deposition and clearance, that about 9% of undissolved particulates are deposited in the uncilliated airways, the welders they studied should have a median thoracic burden of 30 g in the absence of long term clearance. Since they measured levels lower by a factor of more than 10, they conclude that their measurements are compatible with the operation of a long-term clearance mechanism and other animal and human data.

This study did not detect large differences between smokers and non-smokers, in pulmonary function parameters, or self-reported frequency of bronchitis. It is possible that this is a combined effect of the sample size and the inherent uncertainty in the measurement.

An alternative non-invasive approach is described by Stahlhofen and Moller (Ref. 157) and Le Gros et al. (Ref. 87). They used SQUID (superconducting quantum interference detectors) units to detect the magnetic signal from particles magnetized by an external magnetic field.

Le Gros et al. (Ref. 87) studied five non-exposed controls and 13 exposed workers. Calculated lung burdens ranged from zero in controls through 3065 mg in a dental laboratory worker. All the welders in the study were smokers. Three workers described as "Manual Metal Arc/Mild Steel" with exposure durations of 38, 35, and 38 years and measured 2, 1, and 2 years after exposure had levels of 128, 31, and 305 mg of retained magnetic material. These three workers were categorized as having chronic obstructive pulmonary disease. A stainless steel welder with 16 years of exposure had a 435 mg burden and lung cancer (adenocarcinoma).

Stahlhofen and Moller (Ref. 157) describe a SQUID based system with a smaller magnet configuration which has the potential to make more localized measurements that the system described above. They also used inhalation of 1 mg loads of magnetite to test and calibrate their system. They show data for 11 controls, all under 1 mg of magnetic material in the lungs and seven welders with burdens ranging from 10 to approximately 200 mg. The three stainless steel welders had the highest burdens. No information is given about exposure duration, recency, or smoking history.

5.4 Pulmonary Function and Bronchitis. Exposure to asbestos is an occupational condition among welders in some industries, such as shipbuilding. Rosenstock et al. (Ref. 142) compared measurements of pulmonary function with chest roentgenographs scored with the International Labor Office 1980 profusion grade classification system. This scale has 12 levels which range from 1/0 to 3/+ with increasing abnormality. The study population of 684 male union members was made up primarily of marine pipefitters (35%), plumbers (24%), and steamfitters/welders (23%). The x-ray images were coded by trained raters unaware of the other measures. The two observers had good interobserver and retest performance on the ratings. The percentage of the predicted (for their age and height) of forced vital capacity (FVC) was a decrease with an increase in the ILO Profusion Grade. The prevalence of isolated restrictive impairment became greater with increasing ILO Profusion Grade. The authors suggest that the use of the ILO profusion grade of at least 1/1 as a criterion for nonmalignant asbestos disease may be overly conservative because the spirometric measures indicate impairment in lower grade categories.

Funahasi et al. (Ref. 53) studied a set of 10 welders or cutters who had cough or dyspnea (difficulty breathing), or both, and abnormal chest radiographs. Spirometry showed that seven had restrictive pulmonary impairment and two had mild to moderate obstructive impairment. Duration of work in welding or cutting ranged from 8 to 40 years. Lung samples were obtained by biopsy, stained with Prussian blue (to show iron) and scored by two pathologists who were blind as to the clinical history. Tissue elemental microanalysis by energy dispersive x-ray analysis using a scanning electron microscope. Concentrations of silica and iron were normalized to tissue sulfur concentrations to compensate for differences in tissue mass in the areas analyzed.

The Si/S and Fe/S ratios were compared to those from 10 age matched controls and 10 cases of "well established silicosis". The Si/S ratio was not different between controls and welders, but was significantly higher in the silicosis patients. The Fe/S ratio was significantly elevated in the welders as compared with the controls and silicosis patients. This study is interesting because it indicates that pulmonary impairment and symptomology can occur with normal lung silica concentrations, but increased iron levels. This is a highly selected population, however, and does not reflect the incidence of the condition among welders.

Cabal et al. (Ref. 30) studied 986 males involved in metal industries. Respiratory pathology was associated with 15 or more years of exposure and was potentiated if linked with cigarette smoking history. Seven hundred and thirty welders and two hundred and fifty six nonwelders of similar socio-professional class were studied with a questionnaire medical history, chest x-rays, pulmonary function tests, and cytologic examination of sputum. The average age was approximately 37 years with 5–9 years welding as the modal value and manual welding as the most frequent type. The proportion of cigarette smokers of various durations was similar in the welders and the nonwelders studied.

Findings consistent with those of the Cabal et al. study (Ref. 30) were reported by Cotes et al. (Ref. 41). They studied shipyard welders and similarly exposed caulker/burners. 607 males ranging in age from 17 to 69 provided a respiratory questionnaire, clinical examination, and detailed spirometric measurements. Chest x-rays were available from approximately half of the subjects. Subjects over 50 years of age had a 40% prevalence of chronic bronchitis with a relative risk of 2.8 when adjusted for age and current smoking status. This prevalence corresponds to a slightly more than a doubling from the prevalence for workers between 20 and 30 years old. The relative risk of breathlessness of grade three or above adjusted for age followed a similar pattern. For breathlessness, the age adjusted relative risk for welders and caulker/burners versus the other trades sampled was 3.2 for current smokers but not significantly different than 1 for the ex- or nonsmokers. Regression analysis of the radiographic scores indicated that age and exposure to welding fumes accounted for 18% of the variance and that there was no association with smoking or respiratory impairment.

Sulotto et al. (Ref. 162) studied a group of 68 current welders in search of respiratory impairments associated with duration of exposure during the working day or the types of metals used. The average age was about 38 years with a range of 18–54. The average number of years in welding was 13 for both the smokers or ex-smokers (55 cases) and the nonsmokers.

Like Cabal (Ref. 30) and Cotes (Ref. 41), the data from Sulotto et al. suggests interaction between smoking and welding in the development of chronic bronchitis. Twenty-five and a half percent of the smokers had chronic bronchitis but found only in 7.5% of the nonsmokers. Similarly, 85% of the nonsmokers had normal spirometric measures as opposed to 45% of the smokers.

Groth and Lyngenbo (Ref. 59) conducted a large study of cross sectional Danish welders and used electricians as a control group. A total of 2660 metal workers who were either active welders or had been working with welding were studied. Eighty percent had been welding at shipyards and 90% used manual metal arc welding with coated electrodes on mild steel.

Based on responses to a self-administered questionnaire, the welders were divided into high- and low-exposure groups. The welders were slightly older and somewhat heavier smokers so the authors standardized with respect to these variables for analysis of the respiratory symptoms. The majority of the comparisons were done using a Chi-squared analysis of two by three tables (yes/no vs. high-, low-exposed, and controls). The statistical analysis indicates whether or not the null hypothesis that the relative frequencies in the categories are the same.

In all cases described, the welders had higher frequencies than the controls. Welders were significantly different from controls on four symptoms related to the upper airways and six relating to the lower airways. Welders had higher percentages and significant ($p < 0.01$) differences on the prevalence of chronic bronchitis in each category of smoking status (Never Smokers, Ex-smokers, 0–14 gm/day, > 15 gm/day) and in the prevalence of difficulty breathing or wheezing.

This study has a larger sample size than the others and the effect is as one would expect. The analysis is more sensitive, and the differences associated with welding can be picked up in all smoking level groups.

In a related study, Lyngenbo et al. (Ref. 93) studied 74 high-exposed welders and 31 age-matched electricians who had never smoked. The welders were selected for being involved with manual metal arc welding of mild steel, never smoked, and had no known history of exposure to chemicals which can cause lung damage, such as asbestos. The controls were never exposed to welding fumes, never smoked, and were not exposed to chemicals which can cause lung damage. The welders were significantly ($p < 0.05$) lower than the controls on several spirometric measures of lung function including Vital Capacity, Total Lung Capacity, Forced Vital Capacity, Forced Expiratory Volume (1 second), Peak Expiratory Flow, and Diffusion Capacity. Based on the regression equation for vital capacity versus age for the welders and controls, Lyngenbo et al. estimate that the lungs of the welders are physiologically 10–15 years older than those of the age-matched controls.

Chronic bronchitis was found in 16% of the welders and none of the controls. Overall, 90% of the controls had normal lung function as compared to 70% of the welders. Obstructive lung disease was found in 22% of the welders and 10% of the controls.

Kilburn et al. (Ref. 78) studied 144 males on a Monday across a shift with a questionnaire and pre- and post-shift spirometry. A set of 443 Michigan men were used as a model group, as well as, 33 smog exposed Spanish surnamed male hospital employees.

Relative to the Michigan controls (grouped by smoking status), the welders had higher and statistically significant ($p < 005$ Chi-squared test) reports of respiratory symptoms including phlegm, shortness of breath, wheezing, pain, pressure, and heaviness in chest during exertion. Across the shift when compared to the hospital employees, the welders had higher frequencies of respiratory symptoms and reports consistent with metal fume fever.

In another study using the Michigan controls, Kilburn and Warshaw (Ref. 77) used a multiple regression model to study the effects of welding and smoking on pulmonary function. The welders included 151 current cigarette smokers and 43 nonsmokers. Welders were excluded if they had welded less than five years, had worked in shipyards, or had asbestosis signs on chest radiographs. Flows in both groups of welders were below those of the reference group. Welders had decreased midflows and terminal flows but Forced Vital Capacity (FVC) and Total Gas Volume were normal. The cigarette smoking welders decreases were more than additive, that is more than the addition of the effects of welding in nonsmokers and the effects of smoking in nonwelders. The authors conclude that long-term exposure to welding gases and fumes reduces flow in small airways of the lung.

One possibility for reducing lung injury due to industrial exposures would be to conduct effective screening. Schneider (Ref. 149) describes the use of acetylcholine aerosol combined with spirometry to screen for workers with "reactive" airways who are considered more likely to respond to dust and/or fume exposures. This approach appears to need further development before it is likely to become practical in U.S. occupational medicine.

Emmerling et al. (Ref. 47) studied 210 welders from 29 plants. In contrast to Cabal (Ref. 30) and Cotes (Ref. 41), they associated increased prevalence of chronic bronchitis with welding rather than cigarette smoking. Spirometric studies found only minor impairments, but abnormalities were found on 34% of the welder's chest x-rays and only 25% of the reference group.

6. Cancer

6.1 Epidemiologic Studies. Welders are involved in two general classes of epidemiology studies. In one type of study, the connection to welding is because it is one of many occupational categories included in an investigation. These might be termed "welders as workers" studies. In a second type of study, welders are the target population studied. These might be termed "welders as subjects" studies.

Epidemiologic studies have important features and limitations. Two important limitations are exposure assessment and the problem of confounding variables. Studies which rely on self reports to assess exposure have an inherent "noise" introduced at a key point in the process. Confounding variables are ones which are correlated with the independent variable under study and may influence the outcome. Two frequent confounding variables in the welding epidemiology studies are asbestos and smoking.

Asbestos is associated with an extremely specific form of lung cancer, and perhaps other diseases. Smoking is associated with lung cancer, bladder cancer, and several respiratory diseases. In epidemiologic studies involving cigarette smoking, the self reported index of exposure used as the independent variable is often the number of pack-years times (the number of packs of cigarettes per day times the number of years smoked). This means that cigarette smoking will be a confounding variable for studies which attempt to assess lung cancer or respiratory disease.

Confounding variables can be handled in two general ways. The first method is to match the control subjects on the level of the confounding variable. An example would be to compare welders and nonwelders with similar smoking pack-year histories. A second approach is to use statistical procedures to "adjust" for confounding variables. An example of this approach would be a stepwise multiple regression procedure. In this case, independent variables would be added to regression equation and to see if they made a significant contribution to the explanation of the total variance in the dependent variable. In the case of cigarette smoking as a confounding variable, pack-years would be included in the regression equation to adjust or account for the cigarette smoking confound.

6.1.1 Types of Epidemiology Studies

6.1.1.1 Cross-Sectional Studies. A cross-sectional study is one in which a sample of individuals is taken, some with and some without the condition under study. Additional variables are measured and the objective is to determine which variables account for the presence or absence of the condition. In a cross-sectional study, the number of individuals included with and without the condition is determined by the investigator. Suppose an investigator sampled 100 men with pulmonary disease and 100 men without and determined that 80% of the men with pulmonary disease smoked at least one pack of Brand X cigarettes per day for the last 10 years and only 5% of the men without pulmonary disease had this 10 pack-year exposure of any type of cigarette. In this contrived example, the odds of being a 10 pack-year smoker of Brand X cigarettes with pulmonary disease are 90/10 or 9:1, and 5/95 or 0.05:1 without. The odds-ratio, in this case 9/0.05, gives a measure of relative risk, in this case 180, which is an indication of the number of times greater the risk is for those with the risk factor than for those without.

6.1.1.2 Cohort Studies. In cohort or prospective studies, the individuals with and without the potential risk factor under study are followed forward in time to assess the likelihood of the disease under study.

6.1.1.3 Case-Control. In case-control studies, the cases are those who have the condition under study and the controls are otherwise similar individuals who do not have the condition. For example, in a study of welding, the controls might be tradesmen working in the same plant but without exposure to welding.

6.1.2 Epidemiology Studies. Epidemiology studies serve to identify potential causative and confounding variables. Comprehensive interpretation rarely, if ever, is based on a single study. Rather the "weight of the evidence" is considered with both epidemiologic and experimental results to arrive at a conclusion. In general, as an area is investigated by epidemiologic methods over a number of years, increasing sophistication is detectable in the assessment of exposure to the factor under study and especially in the assessment of potential confounding variables. This is a natural consequence of the scientific peer review feedback in the conduct of medical research.

Sample size and statistical power are important concepts to consider in the evaluation of epidemiologic studies. Basically, as the number of separate observations increases, the statistical power or ability to detect differences of a given size increases. It is useful to remember that the traditional index of "statistical significance" of $p < 0.05$ is a statement of the likelihood of a difference as large as observed or larger occurring if the null hypothesis (that there is no difference) is true. It is not an index of effect size (how large the difference between groups in terms of standard error) or the importance of the difference. For example, suppose two investigators study welders. One uses 30 welders and 30 controls and finds no "statistically significant" difference in Health Condition Y. A second investigator studies 3000 welders and 3000 controls and finds a "highly significant, $p < 0.0001$, difference" between the welders and controls for Health Condition Y. This is an example of the effect of sample size on statistical power. The 30 welder example would only be able to detect relatively large (and potentially important) differences while the 3000 welder study can detect very small (and possibly unimportant) differences in Health Condition Y. Because of these considerations, it is usually most useful to look for the "weight of evidence" across studies.

6.1.2.1 Non-Stationarity. Many of the conditions of interest in occupational epidemiology have relatively long latency periods which are measured in years. For example, the latent period for cigarette smoking and cancer is approximately 20 years, on the average. This means that there can be large changes in an industry driven by external factors during the period under investigation. As industrial hygiene conditions improve across industry, it will be more and more difficult for epidemiologic studies to detect differences. It might well be that welding, as practiced in industry in 1940–1960, is associated with some excess risk of some particular health effects but that welding as currently practiced is not.

6.1.2.2 Risk Multipliers. Because disease prevalence and incidence are discussed as rates and risk factors as rate ratios, it is important to consider the absolute level in risk assessment. The total number of individuals affected by a doubling of risk is directly proportional to the absolute rate. If the rate of Health Condition Z is 0.5 per 100,000 and a factor doubles the risk to 1 per 100,000, one's impression is different than if the rate was 4500 per 100,000 without and 9000 per 100,000 with the risk factor.

6.1.3 Welders as Subjects. Tola (Ref. 168) studied 12,693 shipyard and machine shop workers, including 1689 welders. They point out the difficulties in separating the confounding effects of asbestos and smoking from the effects of interest. The expected rates of disease conditions were those for the regional urban area. A small excess risk of lung cancer was observed for the welders in machine shops but not in the shipyard which they suggest could be due to sampling fluctuation. They conclude that the risk of lung cancer associated with this type of welding must be low (because the sample size used would give reasonable power).

Melkild et al. (Ref. 101) studied 4778 male shipyard workers, including 783 mild steel welders. Increased ($p < 0.05$) lung cancer among the cohort (53 observed and 31.3 expected) was mirrored among welders (7 observed versus 3.2 expected). Because the set of welders is much smaller, even though the standardized incidence ratio is higher for welders, it is not statistically significant. The authors conclude that smoking and asbestos exposure are potential confounding variables.

Siemiatycki et al. (Ref. 151) investigated whether or not cigarette smoking was associated with other measures of industrial exposure. In other words, do nonsmokers tend to seek out lower exposures in general? The study of 857 men in Canada ". . . do not support the view that nonsmokers sought out cleaner job environments than smokers; they imply that internal analyses of "dose-response" in cohort studies are unlikely to be seriously confounded by smoking habits." (Ref. 151, p. 59).

Merlo et al. (Ref. 102) studied shipyard welders (253 electric arc and 274 oxyacetylene). It includes a table summarizing 23 epidemiologic studies involving welders between 1954 and 1985, eight of which show an increased relative cancer risk of $p < 0.05$. This study is interesting because the authors assert that the two types of welders experience different levels and types of exposures. The electric arc welders are mainly in open areas on mild or alloyed steels. The oxyacetylene welders' work is described as having higher fume and polycyclic aromatic exposure because of work inside oil tankers. There is a difference in the profile for the two types of welders relative to the expected rates for the Genova Italy urban area. The oxyacetylene welders have an increased risk of respiratory track cancer (12 observed and 5.1 expected) and the arc welders did not (4 observed and 4.5 expected). Similarly, the oxyacetylene welders were at increased risk for bladder and kidney cancer, ill-defined conditions, and all deaths.

Asbestos may be a confounding variable for more than mesotheliomas in epidemiologic studies. Kishimoto et al. describe (Ref. 80) two shipyard workers, one of whom was an arc welder for 40 years with acute myelocytic leukemia. Crocidolite asbestos, the type implicated in mesotheliomas, was recovered from both the lungs and bone marrow. By comparison, 10 lung cancer patients had a wide range of concentrations of asbestos in lung tissue but no detectable asbestos in their bone marrow.

Chronic myeloid leukemia was studied by Preston-Marton and Peters (Ref. 134) through the use of telephone questionnaires. Cases were 137 Los Angeles county residents with histologically confirmed chronic myeloid leukemia. Neighborhood controls were located who were closely matched for age (within 5 years), sex, and race. The questions asked from a script included history of x-rays or radiation therapy and a list of 11 occupations selected for possible association with leukemia risk. Calculation of the crude matched odds ratio was 19 ($p < 0.01$), and with a logistic regression with statistical adjustment for other variables, the odds ratio was 25.4. The 95% confidence interval went from odds ratios of 2.78 to 232.54. This is relatively strong epidemiological evidence of association with welding, which was primarily arc or heliarc. The authors conclude that "The striking frequency of welding occupations in the cases suggests a causal connection between welding exposures (or something very closely associated) and subsequent development of CML. The level of detail of information collected in this study does not shed light on whether gases, fumes, or radiation (whether ionizing or non-ionizing, such as electric or magnetic fields, or both) are responsible" (Ref. 134, p. 108).

Hull et al. (Ref. 69) conducted a case-control study of lung cancer from a population based cancer registry in Los Angeles County. Cases were 128 white welders with a pulmonary malignancy. Control subjects (177) were all other welders with a nonpulmonary malignancy. Three mesothelioma cases were excluded because of the high degree of association with asbestos exposure and 8 subjects were excluded because the primary cancer site could not be determined.

A standardized questionnaire was administered by telephone to a proxy. The actual subject was not interviewed unless the proxy was unavailable or refused. Participation was 70% for cases and 66% for controls. Eight sociodemographic factors reported were not different between cases and controls. The odds ratio for "ever smoked" vs. "never smoked" was 7.6 ($p < .001$) and that for shipyard welding with a first exposure at least 10 years previously was 1.7 ($p < 0.05$).

The authors conclude that "... the excess of lung cancer in this welding population is contributed to by a higher frequency of smoking and probable exposure to asbestos in shipyards" (Ref. 69, p. 103).

6.1.3.1 Summary. These studies do not constitute strong evidence that welding, per se, is associated with lung cancer in the groups studied. In the Hull et al. study (Ref. 69) cigarette smoking among the cases was a larger risk factor than other details examined. The Preston-Martin and Peters study (Ref. 134) is more suggestive because cigarette smoking is not a major risk factor for this condition although, it is possible that asbestos is a confounding variable in this case also (Ref. 80).

6.1.4 Welders as Workers. Welding was grouped with pesticide spraying, locomotor driving, and forestry work, with motorsaw, or herbicides, in a study by Dave et al. (Ref. 42) to look at broad groupings of occupations and cigarette smoking history. A set of 62 lung cancer cases and 198 controls from the same hospital were studied. The odds ratios for the work categories were less than or close to one through the group with welders. The workers with probable exposure to asbestos or mine work had an odds ratio of 3.3 which was not significant a $p < 0.05$. Cigarette smoking was monotonically related to amount of smoking and reached an odds ratio of 5.1 for the heavy smoker category.

Tobacco smoking as a cofactor in lung cancer was studied by Zemla et al. (Ref. 191) in the context of occupations expected to involve dust and air pollution, including welding. A group of 210 male cases and 420 male controls without any cancer were studied. The interaction of smoking and dust exposure did not appear to influence the overall profile of histologic types of lung cancer. When compared to nonsmoking controls, welders who smoked had a relative risk of 2.24 which did not appear to be statistically significant.

Claude et al. (Ref. 34) studied 531 male case control pairs with cancer of the lower urinary tract. Welding did not have significant odds ratio as an "ever employed" category.

Ronco et al. (Ref. 141) conducted a population based case (126 men) control 384 men study in northern Italy. The authors used 15 categories of industrial activity including welding and computed odds ratios by two methods (Mantel-Haenszel and logistic regression). The logistic regressions were adjusted for being engaged in other job categories studied. None of the occupation categories had a $p < 0.05$ for the logistic regression model and only welding (OR = 3.58 with a 95% confidence interval from 1.1 to 11.7) was statistically significant at $p < 0.05$. This study is very weak evidence of an association between welding as an occupational class and lung cancer.

Woods and Polissar (Ref. 188) were studying the occurrence of non-Hodgkins lymphoma (NHL) among farmers in Washington state and included welding/metal fumes as a category under "Other chemicals" in agricultural use. The odds ratio of 1.41 for NHL was not statistically significant.

Six high cancer mortality areas of New Jersey were studied by Schoenberg et al. (Ref. 150) in a search for high-risk occupational categories while statistically controlling for lifetime smoking history. A set of 763 cases and 900 controls were directly interviewed. Controls were selected by random sampling of drivers license files and matched by sex, age, race, and location of residence. As a class, shipbuilding had an odds ratio of 1.6 (95% confidence interval 1.2, 2.2). Welders and burners were examined as a subset of shipbuilding workers and had an odds ratio of 3.8 (95% confidence interval 1.8, 7.8). The job categories used were not mutually exclusive, and some workers worked in multiple job categories. When welders, sheet metal workers, and boilermakers were grouped together, the odd ratio was 3.5 (95% confidence interval of 1.8, 6.6). Subjects in this grouping who did not report asbestos exposure had an odds ratio of 2.5 (95% confidence interval of 1.1, 5.5).

The Missouri Cancer Registry was used by Zahm et al. (Ref. 190) to obtain 4431 white male lung cancer cases and 11,326 controls with other cancers for analysis by 52 occupational groupings including "welders and solders" who had an odds ratio for lung cancer of 1.2 with a 95% confidence interval from 0.7 to 2.1. The welders and solders group had excess adenocarcinomas and squamous cell carcinomas but not small cell carcinoma of the lung.

Ng (Ref. 111) studied occupational mortality in Hong Kong during the time period 1979–1983. A grouping of welders and plumbers had elevated relative age standardized mortality ratios for lung cancer ($p < 0.01$), cancer of the buccal cavity and pharynx ($p < 0.01$) and leukemia ($p < 0.05$).

Black and white males at seven sites in Illinois were studied over the time period of 1979–1984 by Mallin et al. (Ref. 96) based on death certificate data and randomly selected controls of the same age and race. Black welders and cutters had an age adjusted odds ratio of 3 for stomach cancer ($p < 0.01$). Interestingly, deaths from lung cancer were not related to welding.

A large site in Tonawanda NY was studied for its profile of mortality in a search for radiation related contributory risk factors (Ref. 167). There was deficit for all causes of death combined (standardized mortality ratio of 87) and the overall rate of cancer deaths was near the expected number (standardized mortality ratio of 99). Occupational categories by trade were not involved in the analysis but the discussion mentions that one of the observed deaths from connective and other soft tissue cancers was a welder.

California highway workers were studied by Maizlish et al. (Ref. 94) who died in California in 1970–1983. Welding is listed in a table as an activity suspected of association with lung cancer. Among the 1570 workers studied, there was not an excess risk of lung cancer although many other categories of death had excess risks, none appear to be related to welding.

6.1.5 Welders As Parents. An extension of the logic of the case-control studies can be applied to childhood cancers. The question "Is there a commonality in the occupations of the parents of the cases which is not present in the controls?" can be addressed by similar methods. These studies do not address the mechanism on parental interaction which could be mediated by chemical or other exposure of the parent or as an occupational correlate such as bringing asbestos contaminated clothes into the child's environment.

Wilm's tumor is a malignant kidney tumor of childhood. Bunin et al. (Ref. 29) conducted a case-control study of 88 pairs interviewed by telephone. The controls were selected by random digit dialing and matched on area code, exchange, race, and birth date.

Analysis, by job clusters, revealed significant odds ratios during preconception (5.0, 95% confidence interval 1.5–28.6) and pregnancy (odds ratio 4.2, 95% confidence interval 1.2–23.7) for Cluster 6 which is "characterized by exposure to aromatic hydrocarbons, aliphatic hydrocarbons, metals, and inorganic compounds" (Ref. 29), p. 727). Jobs associated with Cluster 6 include machinist, welder, scrap metal worker, paper manufacturing jobs, and paste-up artists. Efforts at more detailed analysis were not informative. Job cluster connections to maternal exposures did not result in significant odds ratios. Although not very specific to welders, this study does suggest a potentially useful clue into the origin of Wilm's tumors.

Childhood mortality to brain cancer was investigated by Wilkins and Koutras (Ref. 185) in association with parental occupation. Cases and controls (matched for age, race, and sex) were obtained from death certificates in Ohio. The cases were all white persons less than 20 years old at time of death from 1959–1978 for whom primary brain cancer was indicated as the cause of death and whose Ohio birth certificate could be obtained and whose birth certificate listed Ohio as the primary residence of the mother.

Controls were randomly selected to find a match on age, race, and sex. Of the 682 potential cases, 491 met all requirements for inclusion. Circumstances of birth such as birth order, birth weight, parental age, and rural-urban factors did not reveal differences between groups.

Structural work occupation had an odds ratio of 2.1 ($p < 0.001$). Subsets of this category with significant odds ratios were electrical assembling, installing, and repairing occupations (odds ratio 2.7, $p < 0.02$), and construction occupations (odds ratio 2.0, $p < 0.05$). Welders, cutters, and related occupations had an odds ratio of 2.7 ($p < 0.076$).

A study of risk factors for childhood liver cancer in the United States and Canada by Buckley et al. (Ref. 28) studied 75 cases and controls from random digit dialing. Primary study hypotheses regarding hepatitis infection, alcohol ingestion, smoking, maternal estrogen exposure, and nitrosamines were not supported. Case mothers reported occupational exposure to metals, including welding or soldering fumes (odds ratio 8.0, $p = 0.01$), petroleum products (odds ratio 3.7, $p = 0.03$), or paints (odds ratio 3.7, $p = 0.05$). The fathers only significant reported exposure was to metals (odds ratio 3.0, $p = 0.01$). Inspection of the detailed table indicated that most of the occupational exposures to metals are other than welding or soldering as shown in Table 13. It also appears that there is a discrepancy between the text and Table 13.

6.2 Metal Carcinogens. Hayes (Ref. 61) reviewed the occupational epidemiology of chromium and respiratory system cancer. He summarizes that studies have shown excess respiratory system cancers in industries where chromium compounds are utilized but that further information is necessary to develop dose-effect information.

Table 13
Exposure Category and Sex of Workers

	Mother		Father	
	Case	Control	Case	Control
Metals	2	1	24	15
Welding	1	0	12	14
Soldering	3	0	9	10

Data from (Ref. 28)

Fairhurst and Minty (Ref. 49) produced a large (243 pages and 858 bibliographic entries) review on the toxicity of chromium and inorganic chromium compounds. Their conclusion about stainless steel welding is interesting: "Several epidemiological studies have been conducted on stainless steel welders, suggesting excesses in mortality from cancers of various areas of the respiratory tract. However, with respect to the effects produced by chromium, these findings are inconclusive, particularly considering the 'mixed-exposure' characteristics of the welding fume (Ref. 49). They do conclude, however, in their summary of carcinogenicity that: "Therefore, it appears that Cr(VI) ions in solution, in the respiratory tract, can cause cancer in humans. Such conditions can be produced by inhalation of Cr(VI) in this form, or in the form of chromium (VI) compounds with an appreciable degree of water solubility" (Ref. 49).

Genotoxicity may be the mechanism leading to metal-induced carcinogenesis, however, the details are not yet understood. Snyder (Ref. 156, p. 237) cites over a dozen studies showing that metal salts can induce DNA damage. In his study, cadmium, magnesium, manganese, chromium(VI), zinc, and selenite were shown by two separate assays to induce DNA strand breaks. These breaks were repaired by four hours after removal of the metal from the culture medium, an important reminder that there are active maintenance systems for DNA. Studies involving inhibition of DNA polymerase suggest that the metal induced strand breaks are more similar to those caused by x-rays than those caused by UV-irradiation. Cr(VI) and cadmium caused detectable DNA strand breakage at concentrations lower than those of the other metals.

The oxidation state of chromium is a major determinant of its carcinogenic potential. Cr(VI) is well-known as carcinogen, and Cr(III) is not. Standeven and Wetterhahn (Ref. 158) reviewed the toxicity of Cr(VI) and the "uptake-reduction" hypothesis. This hypothesis is that the difference in carcinogenicity between Cr(III) and Cr(VI) is due to different access to the interior of cells. They cite evidence that Cr(VI) is taken into cells by a nonspecific anion channel but that cells are relatively nonpermeable to Cr(III). They hypothesize that once inside the cell, Cr(VI) is reduced by glutathione to Cr(III) which is the "reactive intermediate" producing DNA damage such as cross-links, strand breakage, and Cr-DNA adducts.

Wetterhahn et al. (Ref. 181) review a number of biochemical studies which suggest that the "reactive intermediate" from chromium can cause DNA damage which affects the template function of DNA and can cause altered levels of expression of mRNA products. The suggestion implies that the interactions with DNA are not random, but may ". . . target certain classes of genes and lead to changes in their expression" (Ref. 181, p. 406).

A study of the direct molecular interactions of Cr species with nucleotides and nucleic acids provides independent support for part of the "uptake-reduction" model described above. Wolf et al. (Ref. 186) used 31P-NMR spectroscopy to monitor the formation of Cr-nucleotide complexes *in vitro*. Only Cr(III)-nucleotide complexes could be detected. Reduction of Cr(VI) to CR(III) with excess glutathione led to complex formation indicating that the CR(III) was available and not bound to the glutathione in a stable complex. Binding assays using 51Cr(VI) and 51Cr(III) showed that the Cr(III) bound to synthetic nucleic acid polymers and calf thymus DNA, but Cr(VI) binding was not detectable. This is quite direct evidence that Cr(III) is the species which can be demonstrated to interact with biologically important compounds *in vitro*.

Nickel is also a metal carcinogen with an unknown mechanism of action. Inhibition of DNA-protein interactions (Ref. 37) is one possibility and interference with DNA replication by binding where Mg(II) normally binds is another (Ref. 33).

7. Metal Fume Fever

Exposure to metal fumes including manganese, chromium, copper, lead, and zinc (Ref. 85) can produce an acute condition resembling a viral disease with cough, discomfort, and fever. A metallic taste is often reported. Langham Brown (Ref. 85) reviewed the recent medical literature on zinc fume fever in connection with a case description. Metal fume fever with zinc occurs when particles <1 um (which can reach the alveoli) are inhaled and not with oral exposure or when larger particle size zinc oxide is inhaled. Chest radiographs are usually abnormal and an increase in neutrophils is often observed. The condition is usually transient and clears within a few days. Langham Brown (Ref. 85, p. 328) suggests that, because of the clinical and radiographic similarities to allergic alveolitis, there may be an immunologic mechanism.

Noel and Ruthman (Ref. 120) measured serum zinc levels in two cases of metal fume fever and found levels above the normal range. In one of the cases, a repeat measure of serum zinc levels seven months later was within the normal range. The elevated serum zinc levels means that the zinc is being picked up by the serum and probably that urinary excretion is one of the mechanisms of elimination. It means that the zinc is going into solution and is not an inert particle.

Kawane et al. (Ref. 76) in a letter to the editor describe a metal fume fever case and suggest that metal fumes are a potential cause of occupational asthma.

Cadmium exposure from silver soldering led to the hospitalization of a worker described by Ohshiro et al. (Ref. 123). The symptoms were very similar to those described for a metal fume fever including elevated leucocyte count, fever, and abnormal chest x-rays. Unlike typical metal fume fever cases, the patient was severely ill and eventually required a tracheostomy. The diagnosis was interstitial pneumonia. Measurement of blood Cd levels 94 days after exposure showed about five times the normal concentration. The authors estimate that the initial exposure was at nearly a lethal level. Two years after the incident, the victim was still recovering.

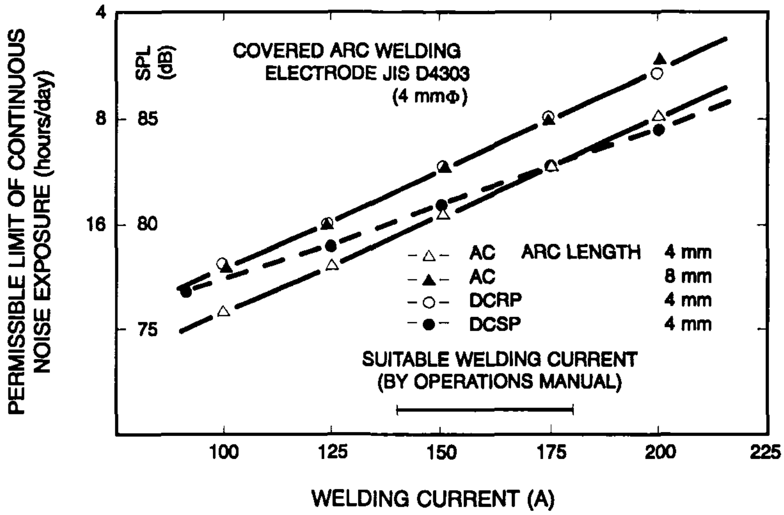
8. Effects on the Ear and Hearing

Excessive sound exposure can impair hearing. Some losses of hearing sensitivity are transient and called temporary threshold shifts (TTS), other losses are permanent and called permanent threshold shifts (PTS). The hearing loss with PTS is associated with damage and loss of receptor cells in the inner ear. The situation is quite analogous with UV light damage to the eye and the safety practice is similar; reduce intensity of stimulation by process modifications or the addition of an attenuator.

Futamata (Ref. 54) has examined several welding processes relative to the ACGIH noise exposure guidelines and expressed the results in terms of permissible exposure times for different welding methods. Figure 2{seq figure arcparam} shows the exposure times relative to arc parameters. CO_2 and MIG results are shown in Figure 3{seq figure co2mig}, and the times for TIG welding are shown in Figure 4{seq figure tig}.

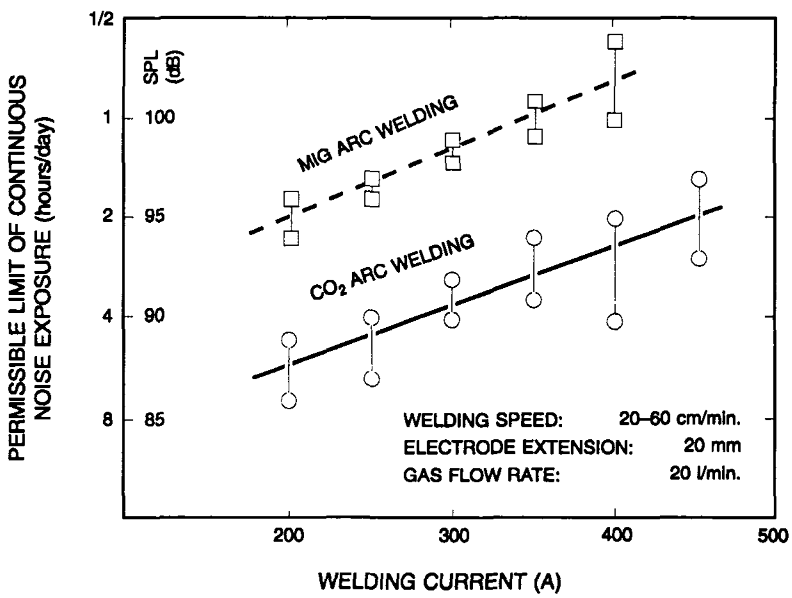
As may be seen from the figures, AC and DC covered arc welding are unlikely to produce excessive exposures during an eight hour shift. Permissible exposure for MIG and CO_2 welding depend on the welding current, and 400 amp MIG welding has a permissible exposure level of less than one hour per day. Pulse TIG welding permissible exposures are a function of the pulse repetition frequency and the waveform of the welding current. For example, with a 100 Hz sine wave, the permissible exposure is over eight hours per day, but for a 100 Hz square wave, the permissible duration is about 1.5 hours per day. At high (> 2000 Hz) pulse frequencies, it is possible to exceed the 115 dB maximum permissible level. The authors measured the attenuation of a welder's face shield and found a reduction of 2–6 dB compared to the attenuations greater than 20 dB obtainable with commercial ear protectors.

The noise produced by welding processes depends on many factors and parameters. Appropriate sound surveys and the use of ear personnel protective devices will help minimize the incidence of permanent hearing loss among workers.



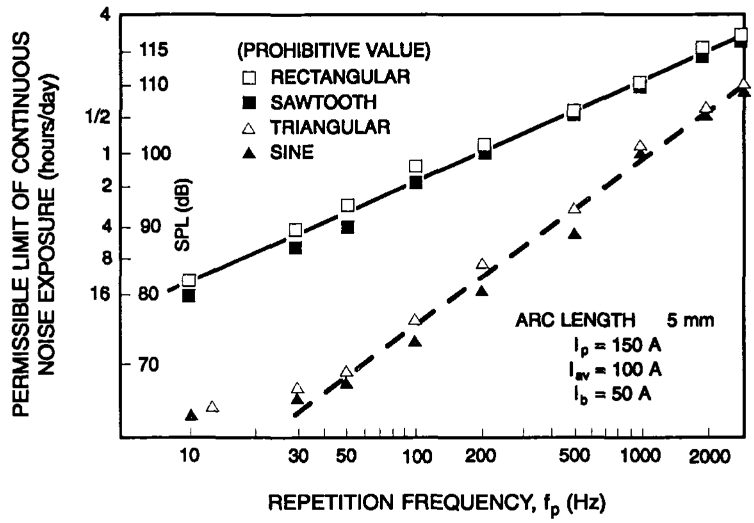
3 PERMISSIBLE EXPOSURE TIMES TO NOISE DURING COVERED ARC WELDING, BASED UPON THE ACGIH STANDARDS.

Figure 2 — Permissible Exposure Duration and Arc Parameters



4 PERMISSIBLE EXPOSURE TIMES TO NOISE DURING CO_2, MIG ARC WELDING, BASED UPON THE ACGIH STANDARDS.

Figure 3 — Permissible CO_2 and MIG Durations



7 PERMISSIBLE EXPOSURE TIMES TO NOISE DURING PULSE TIG ARC WELDING, BASED UPON THE ACGIH STANDARDS.

Figure 4 — Permissible TIG Duration

Ultrasonic welding is used for the joining of plastics and for the attachment of metal parts to plastic. In this process one of the parts is driven by an ultrasonic applicator which transmits vibrations through the part and causes friction heating at the contact area. The softening of the contact area plus pressure complete the weld. The process takes 0.5–2 seconds per weld. When compared to a group of international noise exposure standards, the dominant frequency of the device was the strongest predictor excessive noise levels. The lower the dominant frequency, the more systems exceeded permissible levels. All machines operating at 10 kHz were excessive and none of the machines operating at 30–40 kHz had excessive noise output. The authors recommend engineering controls such as sound attenuating equipment cabinets as preferable to ear personnel protection.

9. Effects on the Eye and Vision

In developed countries, eye protection from radiation is a fundamental element of safety programs. In the United States, information is available in pamphlet format (Ref. 129 and Ref. 11) and as reprints from the Welding Handbook (Eighth Edition) and ANSI/ASC Z49.1-88 (Ref. 1 and Ref. 165). Similar information and standards are available in other developed countries (Ref. 135). In less developed countries, however, relatively large numbers of welders exist who do not wear eye protection and do not understand the need for eye protection. Alakija studied 400 Nigerian welders, primarily users of oxyacetylene welding (Ref. 3) and observed a variety of eye complaints and eye protection practices as shown in Table 14.

As may be seen from the table, not wearing goggles increases the relative frequency of eye complaints. Pterygium is an abnormal membrane from the conjunctiva toward the cornea of the eye.

In a review of optical radiation hazards to the eye, Sliney (Ref. 154) describes three different conditions: (1) photokeratoconjunctivitis ("welder's flash" or "snowblindness") caused primarily by ultraviolet B and C exposure, (2) photochemical injuries such as photoretinitis ("solar retinitis" or "eclipse burn") caused by blue or violet visible light, and (3) thermal injury from brief intense exposures, typically to infrared radiation.

Even in developed countries, retinal injuries from arc welding are reported. Brittain (Ref. 25) reports on two

Table 14
Eye Complaints as a Function of Goggles Use

Goggles	*Pterygium*	*Cojunctivitis*	*Lachrymation*	*Number*
Never	33	32	35	140
Always	11	10	15	260

Data from (Ref. 3)

cases involving untrained welders and metal inert gas welding. Both patients had retinal burns from using the MIG unit without appropriate use of the visual filters. In the first case, the gas used was CO_2 and the retinal burn occurred without keratoconjunctivitis. The author suggests that this is because the emission spectrum of CO_2 produces relatively less ultraviolet than visible and near infrared radiation. In the second case, with argon as the shielding gas, the location of the lesions indicated that the arc was very near the eyes, closer than the point of visual fixation. The author expresses concern that the availability of MIG equipment to the undertrained may lead to an epidemic of macular burns.

Reesal et al. (Ref. 137) conducted an analysis of 1985 workers' compensation claims for eye injury. Approximately 4% of the total claims related to eye injury. In 1985, 21% of all Workers' Compensation Board of Alberta (Canada) for eye injuries were from welders. Most injuries were temporary and 95% of the welders had returned to work within seven days, however, some permanent eye injuries occurred. The cornea was the location of 91% of the injuries at a "single anatomic site". About 25% of the corneal injuries were characterized as radiation injuries (keratoconjunctivitis) resolved without permanent impairment within seven days. Cold metal particles accounted for nearly half of the ocular injuries and a total of 72% of the welders eye injury claims were from foreign bodies entering unprotected eyes. These data indicate that the radiation hazard is recognized, and appropriate protective measures are applied, but that mechanical processes related to welding such as chipping and grinding are the major source of occupational eye injuries in this location.

The numbers provided by Foster for the U.S. (Ref. 52) citing data from the National Safety Council states that 5% of Workmen's Compensation are for eye injuries and that about 41% of these occurred despite the use of eye protection by the victim. These are not directly parallel to the data from Canada because they are not broken down by occupation.

10. Effects on the Nervous System

Multiple sclerosis is a degenerative condition of the myelin sheath of neurons, especially in the central nervous system. Although often considered an autoimmune disease, the cause is unknown. Flodin et al. (Ref. 51) performed a case-referent study of multiple sclerosis patients and included welding as one of the potential risk indicators. The data was obtained from a mailed questionnaire. Welding emerged as an exposure factor with different rates in the cases and referents. The Mantel-Haenszel rate ratio for welding was 2.7 but the 95% confidence interval extended from 1.0 to 7.0. Other factors with similar rate ratios were solvent exposure and radiologic work. Interpretation of this finding will require other epidemiologic studies which include welding status.

The connection between nervous system damage and welding is more clear in a report by Tvedt et al. (Ref. 170) because the patient was exposed to hydrogen sulfide during welding on a sewage pump. The relevant factor in the development of the encephalopathy as diagnosed by neuropsychological tests was hydrogen sulfide exposure, not welding per se.

Similarly, Hodgson et al. (Ref. 66) reported on a persistent vestibular and cognitive dysfunction lasting from 8 to 18 months in three men following aliphatic hydrocarbon exposure. The welder and two helpers entered a 30,000 gallon container which had been previously used for storage of waste oils and welded a flange to the metal tank. The tank had been vented for two weeks, but no atmospheric testing was performed and no respiratory protection was used. The welder rapidly became confused and was taken to the first-aid station. The other two workers attempted to complete the task but soon sought assistance. The three were taken to a hospital emergency room. They were studied three months later because of continued complaints.

The three men were diagnosed as having mild encephalopathy and vestibulopathy. Analysis of the sludge in the tank showed it was (by weight) 42% oil and grease, 22% iron, and 1.7% metals other than iron. Metals implicated in central nervous system encephalopathies or lesions were present at levels below 0.5% in the sludge. The metals analyzed included lead, mercury, arsenic, aluminum, and manganese. Reenactment of the exposure and atmospheric sampling did not lead to identification of chemicals. The only halogenated hydrocarbon found was dichloromethane at the micrograms per kilogram of sludge level. The causative factor in this incident is unidentified.

Rudell et al. and Wenngren and Odkvist (Ref. 144 and Ref. 180) discuss vestibulo-oculomotor problems potentially related to welding. Rudell et al. surveyed 323 welders about symptoms related to welding and found 26 who reported dizziness. Seven of the 26 reporting dizziness did not have a known medical disorder and were selected for experimental study. Welders (7) and matched controls (7) were tested with a battery of oculomoter test before and after 30 minutes of welding. Different welder/control pairs used different techniques including manual metal arc, metal active gas, and metal inert gas welding. Personal samplers were used to collect fume exposure samples. The welders had lower scores than the controls (and other normal subjects) before the welding test. Following the test, four welders and two controls had lower test scores. Iron and manganese were found in all fume samples. Electrodes for welding stainless steel had chromium and nickel in their fumes.

Wenngren and Odkvist (Ref. 180) discuss the same set of welders in the larger context of industrial exposure to solvents and welding fumes and reviews the general issues of metal induced neurotoxicity.

The study of Rudell et al. is especially interesting because of the experimental approach employed. Their use of a questionnaire and follow-up examination gave them a pool of individuals who reported dizziness following welding. They were different from controls and normals and apparently sensitive to the effects of 30 minutes of welding. The use of the selected population can be expected to reduce the variability in the results. It is reasonable to expect that if a random sample of welders was tested, there would be no difference detected across the 30 minute test because 92% of the welders surveyed did not report dizziness after welding and their, presumably unchanged, oculomotor test scores would obscure the change observed in the selected population.

11. Effects on the Musculoskeletal System

Welders were included in a study relating back pain to the "type A" personality as assessed by a questionnaire to measure competitiveness. (Ref. 184). Manual workers categorized at Type A were approximately twice as likely to report back pain radiating down the leg as those categorized as Type AB or B. This relationship was not observed with the sedentary workers studied. The authors speculate that the more competitive type A workers are more likely to use all their strength in task performance.

Schardt et al. (Ref. 146) combined a biomechanical model with work observations to calculate the loading of the lumbar spine of welders and mechanics in heavy construction. According to their model, the lumbar spine is loaded about 16% of the shift on the average. The average duration of loading was less than one minute per occurrence. This type of study could eventually lead to the development of work practices which produce less lumbar loading.

Work position was investigated by Svabova et al. (Ref. 164) for manual arc welding. Based on the angle of the upper arm and the elbow joint, they concluded the position of the arm in arc welding is unfavorable at the beginning of welding whether the welder is sitting or standing. Gas welding has the arm in a more favorable position even though the static load is about twice as large. For welders with heights between 168–179 cm, the authors recommend a working plane of 95–115 cm, corresponding to a work table height of 60–80 cm. Clinical examinations were performed on 71 welders who had been in welding for more than 10 years and who reported musculoskeletal symptoms were clinically examined. Complaints included back pain and pain in elbows, wrists, and arms. The left and right arm difference in degenerative changes was not significant. X-ray findings showed more pathological features with increasing age. The problem with this study is the lack of an appropriate reference group. If, as seems reasonable, complaints of musculoskeletal pain increase with age, then any contribution from welding should be expressed as an increase in complaints relative to those from an appropriate control group.

Wickstrom (Ref. 183) describes the beginnings of an intervention study which meets some of the objections to the study above. The study design includes the determination of baseline values of both back disorders and low-back loads. This will be used for developing interventions designed to reduce back problems. One of the work sites was a 3500 employee shipyard, and welders are included with plumbers in a group for intensive study. Perhaps this work will eventually provide important information about both the frequency of back problems and effective interventions.

Many people are familiar with the rotator cuff syndrome as an affliction of baseball pitchers, but Hviid et al. (Ref. 7) suspect that there is an occupational component, especially in tasks with heavy work above shoulder level, for example, shipyard welders. They indicate that improvements in diagnosis will be useful in improving both clinical practice and insurance declarations.

12. Effects on the Reproductive System

12.1 Male. Environmental factors, such as exposure to lead, heat, and ionizing radiation have been studied as contributors to male reproductive dysfunction. Mortensen (Ref. 109) used a postal questionnaire combined with semen analysis and scoring. The criteria for "poor sperm quality," and hence categorization as a case, was any or all of (1) less than 50% motility, (2) less than 50% normal morphology, or (3) less than 20 million/ml. Table 15{seq table oddsrat} shows the odds ratios and 95% confidence limits for the categories of workers studied.

Table 15
Odds Ratios for "Poor Sperm Quality"

Occupation	Odds Ratio	95% C.I.
Welders	2.00	1.16–3.45
Welders (stainless steel)	2.34	0.95–5.73
Metalworkers/ (non-welders)	1.15	0.88–1.51
Other industrial	0.96	0.80–1.15
Unexposed	1	

Data from (Ref. 109)

In this study, the number of presumably unexposed workers with poor sperm quality was 408 out of 1255 or approximately one third (32.51%). Odds can be computed from proportions by the formula that the odds are the proportion to 1 – the proportion in question. The odds of having poor sperm quality for the unexposed workers are 0.33 to 0.67 or 1 to 2. There were 27 out of 55 welders with poor sperm quality or 49% for odds of .49 to .51 or 1 to 1. The odds ratio is what its name implies, so the ratio of 1 to 1 is twice that of 1 to 2.

It is important to note that most of the confidence intervals include an odds ratio of 1.0 which indicates no statistically significant difference in risk. The basic difficulty with this type of study is that there is a very high rate of the phenomenon under study in the presumably unexposed group. This reduces the sensitivity to detect occupationally induced changes.

A related review article (Ref. 18) reviews identified and suspect workplace reproductive hazards and recommends further research.

Jelnes and Knudsen (Ref. 73) took the approach of comparison of mean or median values of parameters reflecting male reproductive function such as sperm concentration, the percentage of live sperm, the percent immobile, and the percent normal sperm and compared stainless steel welders with nonwelders working (usually) in the same plant. No differences attributable to welding were detected, even in a smaller subsample of 20 manual metal arc welders and 11 external (not workers in the plant) controls. The small sample size means that the comparisons have low power to detect differences.

The differences between the report by Jelnes and Knudsen and the study by Mortensen appear unresolved. Perhaps later studies will clarify the nature and degree of male reproductive risk from welding, if there is any.

13. Clastagenesis

Elias et al. (Ref. 46) sampled peripheral lymphocytes from 55 welders and controls matched for age, socioeconomic status, and smoking status from the same plant. Controls were not exposed to welding fumes. Three subgroups of welders were recognized: (1) Group 1, MMA welders working primarily with mild steel and having mainly iron and manganese compound exposure, (2) Group 2 MAG welders using a cored wire containing nickel who were exposed mainly to iron, manganese, and nickel compounds, and (3) Group 3 GMAW welders using electrodes containing chromium and nickel who were exposed mainly to iron, manganese, nickel, and chromium compounds.

Manganese, nickel, and chromium levels were measured in blood in urine. Chromosome aberrations were analyzed in two laboratories blind to the exposure conditions. Welders (combined) had a higher frequency of total chromosomal aberrations, including gaps, (7.55%) than did Controls (4.62%) which was statistically significant ($p < .0001$). Of the three subgroups of welders, Group 2 (9.7%) was statistically different ($p < 0.01$) than their control subgroup (4.61%) in total aberrations with gaps included and ($p < 0.05$) with gaps excluded.

Group 2 welders were statistically different from controls on values for both serum and urine nickel and manganese. Groups 1 and 3 were different from controls in both urine and serum only in chromium levels.

Kendall rank correlation was used to investigate relations between chromosomal aberrations frequencies and age, daily cigarettes smoked, serum and urine metal concentrations, and duration of employment as a welder. The only significant correlations which did not involve cigarette smoking were in Group 2 between the length of employment as a welder and break frequency (chromatid $r = 0.54$; $p < .005$, chromosome, $r = 0.5$, $p < 0.05$).

Daily cigarette smoking was correlated with aberration frequency in both welders and controls.

The Group 2 welders had higher levels of nickel and manganese in serum and urine, but the frequency of chromosomal aberrations was not rank-correlated with these levels, rather, it was correlated with length of employment as a welder. This suggests that the appropriate metric of dose might be the integral (area under the concentration versus time curve) of nickel and/or manganese.

14. Effects on the Urogenital Tract

Verschoor et al. (Ref. 174) examined renal function using urine samples obtained at the end of the working day at the end of the week. Venous blood samples were drawn the same day. Atomic absorption spectroscopy was used to measure Cr concentrations. Creatine was measured in urine and serum, BUN and total protein in urine and albumin in urine were measured with standard clinical chemistry techniques. B2-microglobulin was measured in urine and serum, retinol binding protein in urine, Immunoglobulin G in urine and serum. Additional urine assays included N-Acetyl-B-D-glucosaminidase, B-Galactosidase, and lysozyme. "Since neither the control subgroups nor the welder subgroups differed from each other with respect to age and smoking and drinking habits. . ." (Ref. 174, p. 68), the groups used were chrome-plating workers, stainless steel welders, boilermakers, and controls. Correlation across all subjects revealed $r=.35$ between urine expressed as ug/g of creatine and serum Cr levels. The renal function parameters were not correlated with urinary Cr levels. Both welders (geometric mean of 3 ug/g creatine and range: 1–62; $n = 38$, $p < 0.001$) and chrome platers (geometric mean 9 ug/g creatine with a range of 1–34; $n = 21$, $p < 0.001$) had urinary Cr levels significantly higher than the controls (0.4 ug/g creatine). Chromium clearance (ml/min) was higher in chrome platers (15.0 ± 12.8, $n = 21$, $p < 0.001$) and welders (14.9 ± 16.9, $n = 38$, $p < 0.001$). On the whole, this study does not provide a great deal of evidence to indicate that stainless steel welders are at risk for kidney pathology from exposure to Cr(VI).

15. Effects on the Immune System

Boshnakova et al. (Ref. 19) conducted an immune system screening of 74 clinically healthy shipyard welders who were 20–53 years old. Serum IgG, IgA, and IgM levels were measured as was the number of total and active E-rosette-forming cells (E-RFC) in the blood. Cell mediated immunity was assessed by using intradermal testing with PPD, candidin D-7, trichophytin D-5, and tetanus antitoxin. A control group of healthy non-welders had the same percentage (95.6%) of workers less than 46 years of age, but neither the number of workers in the control group nor the details of the statistical methods used are reported.

Welders had lower levels of IgG ($p < 0.01$) and IgA and IgM did not differ from the controls. The percentage of active E-RFC was not different between the groups but the percentage of total E-RFC was significantly ($p < 0.001$) lower for welders (50.4 ± 3.7) then the controls (62.2 ± 2.3).

The intradermal test indicated that a significantly ($p < 0.01$) higher proportion of the welders (21.81%) had "signs of cell-mediated immune deficiency" (Ref. 19, p. 380) than did the controls (6.6%).

The authors attribute the differences in immunologic parameters to "occupational factors, such as manganese compounds, vibration, and noise" (Ref. 19, p. 379).

16. Biological Monitoring

16.1 Aluminum. Welders were studied by Sjogren et al. (Ref. 152) before and after an exposure-free period of 16–37 days. Air concentration was measured at the work site of 16 of the 23 workers on the day of the first sample collection. Regression statistics were used to analyze the data. Postshift urine level was primarily dependent on the current air concentration and the level after the period of non-exposure dependent primarily on the years of total exposure duration. The authors conclude that there are at least two physiologic "compartments" that can store aluminum, one with a short half-life and the other with a much longer half-life. They suggest the lungs and skeleton are the most likely candidates for the long half-life compartment. This is a very clever experimental approach that could have widespread application in occupational health studies.

16.2 Chromium. Morris et al. (Ref. 108) examined 36 workers involved to some extent with stainless steel welding and some use of high-chromium welding rods. Although Cr(VI) is mentioned in the introduction, it is not stated whether the method measures Cr(VI) or total chromium. Blood and urine samples were collected. The hematocrit was measured. An atomic absorption method was used to measure chromium in plasma, whole blood, and urine. The hematocrit was used in the calculation of red blood cell chromium by difference of the concentrations in plasma and whole blood. Urinary chromium was expressed relative to the creatinine concentration.

The subjects were categorized relative to their last use of high-chrome welding rods: (A) 1–4 days previously, (B) 4 days–2 months, (C) more than 2 months, or (D) controls, nonwelding employees. Significant differences were not found in blood, urine, or red blood cell chromium between workers whose last high-chrome rod use was more than 2 months previously (Group C) and controls (Group D). Relative to the controls (Group D), plasma chromium was increased threefold ($p < 0.01$) in recently exposed workers (Group A) but not in those 4 days–2 months since exposure (Group B). Red cell chromium, the cell to plasma distribution ratio and urinary chromium were increased at least twofold in both groups A and B.

A single subject was studied before and after making a test weld using 80 high-chrome welding rods. Urinary chromium excretion (relative to creatinine) was increased for 10 days. Plasma chromium levels returned to normal by 10 days. Red cell chromium (nmol/L packed cells) was elevated for 33 days. A second test weld performed 40 days after the first led to increases in the urinary and red cell chromium levels. Based on estimates of the normal rate of creatinine clearance and the volumes of the plasma and red cell compartments, the authors estimate that 90% of the plasma lost in the urine must have been in locations (intracellular or elsewhere) not in the plasma or red cells. In other words, where most of the chromium is located until excretion is not known.

Personal air samplers were used by Minoia and Cavalleri (Ref. 105) to measure the exposure to trivalent and hexavalent chromium in platers and welders. The welders and dichromate workers with similar Cr(VI) exposure had similar urinary concentrations. The urinary levels appeared to reflect Cr(VI) exposure in the breathing zone. Cr(VI) itself was not detected in any of the urine specimens. The authors suggest that it is reduced to a lower oxidation state in the lower urinary tract. They show data graphs showing that, in vitro, Cr(VI) concentration decreases to 20% of starting within 120 seconds of incubation with whole blood, but is decreased less than 20% by 20 minutes of incubation with plasma.

Emmerling et al. (Ref. 47) observed their highest Cr(VI) concentrations in association with manual metal arc welding and a correlation between external exposure and post-shift Cr and Ni in urine.

Lindberg and Vesterberg (Ref. 91) studied the excretion of chromium in chromeplaters following temporary cessation of exposure. Over a weekend, the excretion of chromium in the urine in six chromeplaters decreased with a median half-time of 60.5 hour. Measured across a 31-day vacation, the median half-time was 15 days. The authors consider their two compartment model an approximation of a more complex system of compartments with different excretion rates. The authors reviewed earlier studies of urinary chromium excretion in welders and found the excretion parameters to be similar for similar time period of nonexposure.

An interesting difference in the pattern of excretion for the reports on welders and the platers was noted by the authors. The chrome platers tended to have higher urinary chromium concentrations on the morning following a workday than at the end of the day. Their Figure 2 (Ref. 91, p. 488) clearly shows this effect for a selected individual chromeplater. The authors suggest that the chromeplaters have substantial absorption of chromium from the skin and imply that welders do not. A second difference is that the chromeplaters urinary chromium excretion had reached levels as low as unexposed referents after the one-month vacation. In the reviewed study, retired welders four years after last exposure had urinary chromium levels similar to those of welders after a one-month vacation. Lindberg and Vesterberg speculate that there may be a third compartment in the lungs from which chromium is released very slowly from a matrix of iron oxide.

In any event, this paper is an example of the importance of studying specific occupational groups because all "exposures" to the same chemical are not equivalent.

16.3 Nickel. Angerer et al. (Ref. 9, p. 86) measured plasma and urine nickel concentrations in a group of 103 MMA or MIG welders. Foundary workers were used as a comparison group and 26 serum or whole blood measurement papers are tabulated for unexposed persons. Only one of the 26 reports has a level higher than the 4.8 ug/L reported for the welders. However, the authors point out that their measures are in plasma and that "according to one of our results nickel could not be found in erythrocytes" and that correcting to whole blood would give a level of about 2.4 ug/L which would be in about the middle of the nine whole blood measures tabulated from the literature. Their point seems to be that the nickel can be measured and monitored, not that the levels observed are different from the levels of the unexposed.

16.4 Lead. Lead is used in a variety of manufacturing processes including soldering, and automotive and battery manufacture. Kononen et al. (Ref. 83) studied trends in air PbA and blood PbB levels experienced by approximately 10,000 automobile manufacturing workers. Figure 5{seq figure lead} shows that both the air and blood levels have been declining over the time period 1981–85. This suggests that general industrial hygiene improved during the time period studied.

17. In Vitro Studies

17.1 Mammalian Cell Studies. Three in vitro studies of welding fumes using different cellular systems arrived at the same conclusion: fumes from manual metal arc (MMA) welding of stainless steel demonstrate the greatest toxicity in the test systems. The use of different test systems provides converging evidence that may eventually prove useful in risk assessment. The following studies all use welding fumes collected from various processes on filter paper for later use.

Stern et al. (Ref. 160) performed an in vitro cytotoxicity assay using BHK (baby hamster kidney)-21 cell line and SHE (Syrian hamster embryo) primary cells. Eighteen different combinations of welding method (MMA, MIG, MAG) and material (mild steel, stainless steel, or aluminum) were sampled. They also used metallic compounds representative of fume components as controls (Fe_3O_4, MnO_2, $K_2Cr_2O_7$, and NiO). The fume samples were processed by centrifugation and resuspension into total, soluble, and insoluble fractions at different concentrations into test solutions in 1 ml volumes of medium normalized to the test concentrations for total fume. This approach permits separation of the contribution of the soluble and insoluble components.

The main conclusion is that MMA of stainless steel is toxic at the lowest concentrations and that the toxicity is associated with the soluble Cr(VI) component. MIG of stainless steel fumes are cytotoxic at substantially higher doses and the fumes from welding of mild steel are toxic at high concentrations if there is a phagocytotic pathway in the assay so the material can enter the cells as in the BHK and SHE assays.

Sister chromatid exchanges in Chinese hamster ovary (CHO) cells were studied by Raat and Bakker (Ref. 136) using fumes collected under total of 10 conditions (4 MMA of stainless steels, 2 MMA of mild steel, 1 MMA of cast iron, 2 MIG of stainless steel and 1 MIG of mild steel). K_2CrO_4 in two concentrations was used as a reference clastogen in each assay. With the exception of MIG of mild steel, all the other suspensions showed concentration related increases in SCE with virtually all reaching a doubling of baseline SCE levels.

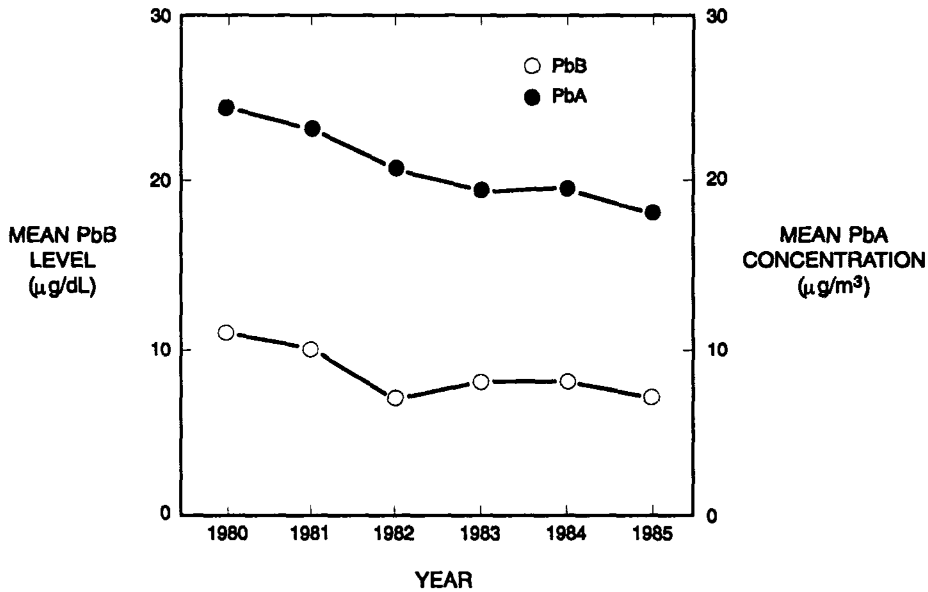


FIG. 1. MEAN YEARLY PbB LEVELS (μg/dL) OF WORKERS IN FOUR PLANT TYPE AGGREGATES, 1980–1985.

Figure 5 — Air and Blood Lead Levels Across Time

The MMA of stainless steel groups were active at concentrations approximately 100 times less than all other active samples. Potassium chromate (K_2CrO_4) was used as a positive control to measure inter-assay variability and permit scaling for the contribution of soluble Cr. The authors conclude that "Chromium appeared to be responsible to a large extent for the effects of the MMA-SS fumes. The variation in the effects per ug chromium is much larger for the suspensions than for chromate, which suggests that the effects of the suspensions are not simply the result of a single chromium species" (Ref. 136, p. 195).

Alveolar macrophages were studied by Hooftman et al. (Ref. 67) using fume samples obtained under 12 welding conditions (4 MMA of stainless steel, 2 MIG of stainless steel, 3 MMA of mild steel, 2 MMA of cast iron, and 1 MIG of mild steel). They used 1–4 um glass beads as negative controls and K_2CrO_4 as a source of Cr(VI) and $CrCl_3$ as a source of Cr(III). Two endpoints, viability and phagocytosis were assessed. Viability was assessed by trypan blue exclusion and phagocytosis was assessed by the uptake of carbonized latex microspheres. The MMA of stainless steel samples had LC50 (concentration at which 50% cell lethality occurs) of less than 30 ug/ml. The Cr(VI) LC50 was about 2 ug/ml. The CR(III) LC50 was about 160 ug/ml. With the exception of one of the MMA cast iron samples (approximately 270 ug/ml), all other specimens had an LC50 greater than 320 ug/ml. These results suggest that Cr(VI) is the cytotoxic component.

The pattern of phagocytosis EC50 (concentration which reduces phagocytosis to 50% of control) values are parallel (but at lower absolute concentrations) to those for cell lethality. Cr(VI) had the lowest EC50 by an order of magnitude, again suggesting that it is the active component.

An English language summary of a Russian report (Ref. 56) asserts that the cytotoxicity of welding dusts to embryonal fibroblast cell cultures is a function of the solubility of the dust components in the culture media.

Costa (Ref. 39) reviewed in vitro models of Ni induced carcinogenesis and concluded that phagocytosis of water insoluble nickel compounds into cells is an important aspect of the neoplastic transformation in the Syrian hamster embryo cell-transformation assay. Interaction with DNA may be through interference with magnesium binding sites and inhibition of DNA polymerase in restricted regions. It is also possible that the interaction on nickel and DNA could lead to loss of a cancer suppressor gene which would give rise to a heritable defect.

Sunderman (Ref. 163) also reviewed mechanisms of nickel carcinogenesis and suggests that the evidence available is compatible with the concept that the carcinogenicity of nickel compounds is a function of their ability to provide Ni2+ ions at critical points in the cell. In addition to the phagocytotic mechanism described by Costa above, he cites evidence that Ni2+ can cross cell membranes through Ca2+ channels, although perhaps attaining lower intracellular concentrations. He lists a set of potential initiating actions: 1) mutagenicity, 2) chromosome damage, 3) inhibition of DNA incision repair capability, and others. It is also possible that nickel can play multiple roles in the induction of cancer, possibly involving both initiation and promotion.

Coogan et al. (Ref. 38) reviewed the toxicity and carcinogenicity of the nickel compounds. In sufficient concentrations, nickel can cause kidney damage, teratogenesis in several species of animals, liver toxicity, and immune effects including contact dermatitis or asthma and immunotoxicity per se. The authors suggest that one of the roles of nickel in cancer may be related to immunosuppressive properties "... which include depression of interferon production, inhibition of phagocytosis by macrophages, suppression of antibody production, and suppression of T-lymphocyte-mediated reaction and NK {natural killer} cell activity" (Ref. 38, p. 357). The authors conclude that the primary concern with nickel compounds is not acute toxicity, but the ability of some nickel compounds to induce cancers.

17.2 Hyperbaric Pressure. Welding under hyperbaric conditions, as in an underwater habitat, can lead to simultaneous exposure to fumes and to high pressure. Jenssen and Syversen (Ref. 74) extended their previous finding of more than additive interactions of high pressure and chromate on cells in culture to the study of the interactions of high pressure and vanadium. In the case of vanadium, high pressure reduced the inhibition of cell growth produced by the same vanadium concentration at normal atmospheric pressure. The authors suggest that the high pressure may influence the availability of vanadate to the cells.

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