



# Effects of Welding on Health, V



**American Welding Society**

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

# Effects of Welding on Health – V

Research performed by SRI International, Menlo Park, California, under contract with the American Welding Society and supported by industry contributions.

An updated (July 1982–June 1984) literature survey and evaluation of the data recorded since the publication of the first report (1979). Some references to papers at an international conference held in February 1985 are also included. This series of reports is intended to aid in the understanding of the health effects of welding.

Performed by:

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**January, 1986**

## **Abstract**

This literature review with 105 citations has been prepared for the Safety and Health Committee of the American Welding Society to provide an assessment of current knowledge of the effects of welding on health, as well as to aid in the formation of research projects in this area, as part of an ongoing program sponsored by the Society. Previous work has included studies of the fumes, gases, radiation, and noise generated during various arc welding processes. Referenced materials are available from SRI International.

Prepared for  
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International Standard Book Number: 0-87171-275-X

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# Personnel

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## Foreword

(This Foreword is not part of the *Effects on Welding on Health-V* but is included for information purposes only.)

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 reports titled *Effects of Welding on Health*. Four volumes have been published to date. The first covered data published prior to 1978, while the next two covered the periods 1978 to May 1979 and June 1979 to December 1980, respectively. The last of the four included information that was published between December 1980 and June 1982. All should be read in conjunction with the current volume 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 impact on the control technologies necessary to protect the welding worker (the Exposure). Much recent research has focused on chromium and nickel, since exposure to certain chemical forms of these metals may cause serious chronic health problems.

In keeping with previous volumes, the health studies are organized according to the organ system affected (*Investigations in Humans*). The respiratory tract, the primary route of entry of welding fumes and gases into the body, also is a major target organ of a number of components of these emissions. Acute (e.g., metal fume fever, cadmium poisoning) as well as potential chronic respiratory effects (e.g., emphysema, cancer) of welding emissions are of concern. The latter are far less well understood and whether or not there is an excess risk of cancer from these exposures has not been established. Continued research in the form of epidemiologic studies, investigations with laboratory animals, and *in vitro* genotoxicity studies will help to resolve this question (*Experimental Investigations*).

## Acknowledgments

Funds for this project were provided by 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  
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Many other organizations have made contributions to support the ongoing program from May 1979 to the present.

## Comparative Listing — Welding Processes

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

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

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

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# Technical Summary

## The Exposure

**Fumes.** A substantial amount of work has been reported on the factors influencing fume formation, including voltage, current, shielding gas, and electrode composition. In a series of reports, Gray et al., have presented data on both total fume formation, fractionated (elemental fractions) fume formation rates, and factors that influence those rates. Other authors (Tandon et al., 1983, 1984; and Kobayashi et al., 1981, 1983) have also presented substantial bodies of data. The effects of current and voltage appear not to be linear—maxima and minima appear as the voltage and current are increased from minimum acceptable levels through the working range. Tandon also confirmed the empirical observation that inexperienced welders produce substantially more fume than experienced workers do.

Work has continued on the evaluation of methods for chromium analysis. Moreton et al. (1983) presented the results of a major interlaboratory/intermethod round-robin exercise in which several methods for Cr(VI) and Cr(III) analysis were compared. This topic has also been discussed by others, notably Gray et al. (1983), Stern et al. (1984), and McIlwain and Nuemeier (1983). The reasons for preferential formation of Cr(VI) in fumes and the sampling/analytical artifacts introduced by some commonly used methods are beginning to be more thoroughly understood, although significant differences of opinion among the active workers in the field are still apparent.

**Gases.** Although gases have not received the recent attention that the fumes have, a fair amount of valuable work has been reported. Press and Florian (1982), Ditschun (1983); Downey et al. (1983), and Faggetter et al. (1983) have reported on mechanisms of gas forma-

tion, engineering methods for exposure control, and sampling and analytical methods. Both oxides of nitrogen and ozone have been addressed; the control measures found to reduce ozone have been addressed; the control measures found to reduce ozone levels have sometimes increased the levels of nitrogen oxides, although promising results in terms of reducing both compounds have been obtained by increasing turbulence in the outer layers of the shield envelope.

**Electromagnetic Radiation.** An interesting finding on the time-course of UV exposure was presented by Eriksen (1985). He found that the initial period of arc ignition may be characterized by an overshoot (as much as ten times the steady-state value) of UV irradiance, leading to eye risks for welders even though the steady-state values were not excessive. The implications for tack welders and their assistants were pointed out.

**Noise.** Eichbauer and Schmidt (1982) have studied the effects of various welding parameters on noise levels. There are substantial differences between manual metal arc (MMA), GMAW, and gas welding in the effects of such variables as workpiece thickness and form of the weld.

## Effects of Welding on Human Health

**Cancer Incidence.** Despite the advances made in recent years in studies of the relationship between welding environment and health, gaps in knowledge remain, possibly because there are few unique or specific diseases caused by the chemical agents associated with welding. Many of the diseases can be related to factors other than chemical in the welding environment; this can confound

the relationship between exposure and the disease that develops. For example, in this review, one important confounding factor for respiratory tract diseases, the smoking history of welders, has not been consistently available to researchers evaluating welding effects. This difficulty can be overcome if the magnitude of the observed risk is very great or if a dose-response is observed, either as a function of years of welding or as a function of the intensity of the welding tasks. Unfortunately, as discussed below, some of the associations observed are very weak, leading some investigators to conclude that some other underlying factor has been responsible for the increased incidence of cancer observed. Studies that clearly define working conditions, exposure levels, welding materials, and general health of workers, including medical and smoking history, and history of their exposure to asbestos are necessary in order to separate the possible synergistic effects.

An examination of the occupational exposure of welders to chromium and nickel is under way (Waddington et al., 1984). If this study redresses the limitations of previous studies, it may be possible to determine the extent of the health hazard posed by welding fumes.

**Cancer of the Nasal Passage.** Hernberg et al. (1983a and 1983b) observed that patients with nasal cancer were more than twice as likely to have an occupational history of welding as patients with cancer of the colon or rectum. Whether this represents a decreased risk of colon/rectal cancers or a greatly increased risk of nasal cancer could not be determined from these studies.

**Cancer of the Larynx.** A weak association of welding and all cancers of the larynx was found both by Olsen et al. (1984) and Sjögren and Carstensen (1985). Olsen et al., also found that the risk of cancer of the larynx increased with the number of years of employment as a welder, particularly with the number of hours per week spent welding. Olsen et al., also found a strong association of welding exposure and the rare subglottic laryngeal cancer; the increased risk with exposure to welding dust was seen only in smokers.

**Lung Cancer.** A number of studies have reported either no increase risk of lung cancer or a slight to moderate increase in welders.

In a case-control study in Tidewater, Virginia, where shipbuilding had been a major source of employment, Blot et al. (1980), found that a small excess of cases had worked in a shipyard as a welder or burner. Similar findings of slightly elevated risks among welders were made by Sjögren and Carstensen (1985), Sjögren et al., (1985), and Gallagher and Threlfall (1983). In contrast, McMillan and Pethybridge (1983) found no excess risk of lung cancer among welders, and only a slight excess

risk was observed by Newhouse et al. (1985). Results of some studies in progress may help clarify the relationship of welding and lung cancer and determine whether the increased risk is due to exposure to asbestos, which has previously been proposed as contributing to lung cancer.

**Mesothelioma.** Barnes (1983) and McMillan (1983) published case reports of five and seven welders, respectively. McMillan and Pethybridge (1983) found an increased proportional mortality among welders in shipyards compared with that in other shipyard workers who are known to be at increased risk of mesothelioma. However, in each case, asbestos exposure was shown to be responsible for the increased risk.

**Kidney Cancer.** Sjögren and Carstensen (1985) found a weak association with kidney cancer among welders identified during the 1960 Swedish census and subsequently followed for cancer. Because the association is weak, it may be explained by a common underlying factor, such as smoking.

**Brain Cancer.** Englund et al. (1982) found a 35 percent excess of observed to expected brain cancer in Swedish welders and gas cutters. In an apparent later follow-up by Sjögren and Carstensen (1985), this excess had decreased to 20 percent. Because this relatively weak association could be explained by a common underlying factor, further work needs to be done to confirm this finding.

**Hodgkin's Disease.** In a proportional mortality analysis of deaths in British Columbia between 1950 and 1978, the deaths among welders from Hodgkin's disease were nearly 2.5 times the expected number (Gallagher and Threlfall, 1983). The authors recommended confirmation of this finding through better designed studies.

**Diseases of the Respiratory System.** McMillan and Pethybridge (1984) found a higher prevalence of dyspnea and mixed pulmonary disease in shipyard welders than in controls. All of the men had been MMA welders, usually with mild steel, for an average of 33 years. However, a higher incidence of pleural plaques in the welders indicated that there had also been higher exposure to asbestos. Results of a clinical study planned to assess the acute and chronic effects of welding on the respiratory system (Waddington et al., 1984) may help to eliminate the confounding effects of asbestos.

Results of several studies were available only in abstract form. In a study of mild-steel welders, Newhouse et al. (1985) reported excess mortality from pneumonia. Mur et al. (1985) reported slight, but nonsignificant, excess in bronchitis and specific radiological abnormalities and significant impairments of pulmonary carbon monoxide transport in welders, particularly

those who smoked. On the basis of this study, the authors recommended that a carbon monoxide transport test be used to monitor pulmonary function in welders.

Fawer et al. (1982) reported that welders had more sick days, sickness absences, and length of absence per episode of illness because of respiratory disease than did control workers. It is not clear how clinically significant these increased absences are in terms of long-range health effects. As a result of an extensive study of respiratory symptoms and pulmonary function in MMA welders, Kalliomäki et al. (1982) concluded that welders could not be considered a homogenous group with respect to exposure and possible health-associated hazards. Pulmonary function of mild-steel (MS) welders was apparently more seriously affected than that of stainless-steel (SS) welders. However, the study relied on self-administered questionnaires and clinical and laboratory results from various sources that may or may not have been comparable. In a follow-up of this study, pulmonary function values were significantly below normal in retired welders, whereas values in younger welders were within normal limits.

Boylen et al. (1984) determined the acute effects of different welding-generated fume during welding on aluminum, stainless-steel, and mild-steel shipyard welders. From the information presented in the abstract, it appears that symptoms of pulmonary irritation and metal fume fever were more associated with aluminum welding than with SS or MS welding.

**Effects on the Cardiovascular System.** The chemical composition of aerosols generated by high alloy steel was implicated in metabolic changes in the cardiovascular system and neurocirculatory history of welders. The differences found in the pathology were attributed to the high chromium and manganese content (Krasnyuk et al., 1985).

**Metal Fume Fever.** Metal fume fever has been reported in welders exposed both to zinc fumes (Ulvik, 1983) and aluminum fumes (Boylen et al., 1984). In one case report (Ulvik, 1983), a welder was occupationally exposed for five hours to fumes containing 35 percent zinc, according to analysis. The fact that the welder's serum zinc levels were found to be lower during the acute phase of the fever supported the hypothesis that increased serum zinc is not part of the pathogenic mechanism in zinc fever.

**Diseases of the Kidney.** Although epidemiological evidence of association between kidney disease and exposure to metal welding fumes is still generally lacking, a recent study noted a correlation between exposure to cadmium-oxide exposure and chronic renal tubular dysfunction in welders. The role of SS welding and, more specifically, chromium in kidney dysfunction remains to be resolved.

**Biological Monitoring.** Ever since it has been known that the working conditions of welders are variable from workplace to workplace, there has been a continuing search for methods to establish more exact dose-relationships between welding fume exposure and health effects. From the results of the studies reviewed here, it is apparent that further baseline work is required.

The kinetics of chromium excretion was investigated by measuring urinary chromium levels. Welinder et al., 1983 demonstrated a two-compartment model for elimination of chromium: a fast-elimination compartment consisting of a chromium half-time that correlated with chromium in the personal air and a slow-elimination compartment that was more approximate and depended on the degree of previous exposure. From this work and the work of Rahkonen et al. (1984), it was apparent that a single urinary measurement was not sufficient to estimate chromium exposure. Mutti et al., (1984) determined that urinalysis was most suitable for the estimation of water-soluble, hexavalent chromium. Correlations were found between chromium and hexavalent chromium in personal air samples and blood levels, but more work in this area is needed.

Nickel concentrations in the urine correlated well with personal air concentrations, but nickel concentrations in whole blood did not differ between welders and controls (Rahkonen et al., 1983).

Sjögren et al. (1983b) found that aluminum levels in urine, but not in blood, were correlated with years of welding experience. Measurements of urinary levels of fluoride also proved a useful way to measure exposure to fluorides (Sjögren et al., 1984). The possibility of monitoring individual manganese exposures from concentrations in biological fluids was found to be complicated by the wide interpersonal and intrapersonal variations in observed concentrations.

Because previous studies have found that cadmium exposure is not reflected in urine or blood levels, a neutron activation technique was investigated for its potential to monitor cadmium levels (Baddely et al., 1983). This method shows some improvement over the use of either urine or blood for monitoring subtoxic exposures to cadmium.

**Estimation of Retained Particles in the Lung.** Studies using magnetopneumography have shown that increased magnetic retention in lungs occurs in welders, and that the amount of retention is related to the number of years of welding (Naslund and Hogstedt, 1982; Hogstedt et al., 1983; Freedman, 1982, 1984). As previous studies have shown, smokers were observed to have lower levels of remaining ferromagnetic material in their lungs (Naslund and Hogstedt, 1982). To derive a median inferred-lung burden for welding fumes, Sten et al.

(1985) used a new magnetopneumographic field technique based on an alternating-current susceptibility bridge to measure magnetic retention. Even though they found a high degree of correlation between median inferred-lung burden of welding fumes and relative lifetime occupational exposure in nonsmoking welders, no difference was observed in chronic bronchitis incidence or some lung-function measurements. This, in effect, precludes its use in detecting clinical abnormalities until further baseline studies can be conducted.

## Experimental Investigations

**Animal Studies.** The possible carcinogenic effects of welding fume particles have been examined in hamsters and rats. After repeated weekly intratracheal instillation of fumes generated from manual metal arc (MMA) or metal inert gas (MG) welding, interstitial pneumonia, alveolar bronchiolization, and emphysema were observed after welding fume particles containing chromium were implanted in the bronchi for 34 months. The relevance of negative results in this study may be questionable because the implantation technique may not adequately mimic true human exposure conditions.

Pneumonitis or lung damage was observed when rats were treated with the constituents of welding fumes generated from various kinds of welding (Hicks et al., 1984; Al-Shamma et al., 1983; Kennebeck, 1985). Stainless steel welding particulates appeared to induce greater and longer-lasting effects in rat lungs than did mild-steel welding particulates, although each fume constituent had distinctly toxic effects when it was administered either intratracheally or by inhalation.

Hexavalent chromium compounds appeared to be the most acutely toxic of a variety of trivalent and hexavalent chromium compounds that were administered intraperitoneally to male and female mice. However, in subchronic studies in mice by the same route of administration, trivalent compounds were retained in the body at a rate of 6.5 times higher than that for the hexavalent chromium compound at 21 days. Excretion of hexavalent chromium was much faster in both the urine and feces of mice. The low initial retention of hexavalent chromium is attributed to its low ability to form coordination compounds at physiological pH (Cryson and Goodall, 1983).

Several studies reported on the comparison of retention in the lungs of rats after their exposure, by inhalation, to MMA/SS and to MMA/MS welding fumes. Alveolar retention of welding fume particulates was much higher in rats after exposure to MMA/SS fumes. This probably reflects increased clearance of MMA/MS fume particles, a finding that agrees with earlier observations on welding fume particle retention in welders. Iron concentration in the lungs was significantly higher in rats exposed to MMA/MS fumes than in controls, but MMA/SS welding fumes did not significantly affect total iron concentration.

**In vitro Studies.** A mutagenic effect due to MMG/SS welding fumes was demonstrated in a modification of the Ames *Salmonella typhimurium* assay that used freshly generated welding fume collected in an impinger (Stern, 1983). Nickel in MIG/SS welding fumes and hexavalent chromium in MMA/SS fume were hypothesized to be the active components in transforming BHK-21 and Syrian Hamster Embryo (SHE) cells in culture (Hansen and Stern, 1983, 1985). Neither trivalent chromium nor MMA/MS fume was active in these mammalian cell transformation assays.

No significant increase in the number of cells with chromosome aberrations or sister chromatid exchanges (SCE) was observed in the peripheral lymphocytes of two different groups of MMA/SS welders (Littorin et al., 1983; Hugsafvel-Pursiaien et al., 1982, 1983). Although negative results in this assay system may not be relevant to the question of genotoxicity of welding fumes in man, it is worth noting that in both studies there was a significant positive association between smoking and the frequency of SCE within both the welders and control groups.

MMA/SS, but not MIG/SS, welding fumes did induce a higher frequency of SCE in an *in vitro* cell system using Chinese hamster ovary cells (Reuzel et al., 1985).

Welding fume particles, especially fumes from SS welding, were toxic to pulmonary alveolar macrophages when tested in an *in vitro* system (White et al., 1984). Hexavalent chromium in concentrations equimolar to the stainless steel was less toxic than the whole particulate, but trivalent chromium was nontoxic at equimolar concentrations. These observations were confirmed by Hooftman et al. (1985).

# Effects of Welding on Health V

## 1. The Exposure

### 1.1 Fumes

**1.1.1 Effects of Voltage and Current.** In an investigation of the mechanisms of fume formation in MMA welding by Gray et al. (1983), it was found that increases in arc voltage increased the formation of the flux and metal fractions of welding fume. With increasing voltage, the proportion of flux fume increased slightly, and proportions of the less volatile elements such as Fe, Ni, and Mo increased at the expense of the more volatile elements such as Cr and Mn. The mechanism for the effect of voltage on the fume formation rate was partly explained in terms of arc temperatures and exposed surface areas of the flux and metal, oxygen partial pressures near the metal surfaces, and the frequency and severity of physical processes. However, it should be noted that Kobayashi and Suga (1981) observed no relationship between voltage and arc temperature. A change of current at fixed voltage was found by Gray et al., to have "...little or no effect..." (on fume formation rate), while Kobayashi found that there was a minimal, although positive and consistent, increase in temperature with current and a strong effect of arc temperature on fume formation rate.

In the MIG welding process, as described by Gray and Hewitt (1982), explosive evaporation and fume from spatter result in unfractionated fume formation. Thus, relatively nonvolatile metals, such as nickel and molybdenum, are found in the fume in concentrations far above those expected on the basis of their vapor pressures. The effect of voltage in MIG welding was found to be primarily on the overall fume formation rate, not on the fume composition [although the comments below on Cr(VI) should be seen]. The fume formation rate (FFR) was described as exhibiting an "N" shaped relationship in which the FFR reached a maximum as the voltage was

increased to 30 volts, followed by a drop to a minimum at about 43 volts which was then followed by a rapid rise as the voltage was increased to above 50 volts. The effect of voltage increase on Cr(VI) percentage of the fume when MIG welding stainless steel was to increase the Cr(VI) content to a maximum at about 20V, followed by a sharp decline as the voltage approached 40V.

Malmqvist et al. (1985) confirmed previous findings that the highest fume emissions are found in SMAW and GMAW of aluminum. The fume emission rate was determined primarily by welding current. Welding voltage and current were both reported to have dramatic effects on the elemental composition of the fume.

Tandon et al. (1983) studied the effects of current and voltage over a wide range (80–120 A, 20–40V) in MMA welding and determined that an optimum arc length minimized fume generation. The rate of fume generation varied so critically with arc length that even an experienced welder might choose to operate under conditions that would result in substantially more than the minimum rate of fume generation. An inexperienced welder using the same machine setting might easily produce fume at twice the minimum rate. Fume generation rates for welding from a single type of stainless steel electrode were found to be 4 times greater under high voltage conditions and 1.5 times greater under low voltage (short arc) conditions than the minimum fume generation obtained under optimum arc length.

Tandon et al. (1984) studied the effect of electrical variables on fume generation rates and electrode melting rates for hardfacing chromium and manganese and high-strength low alloy steel electrodes. In their work, they found that fume generation rates (FGR's) varied by a factor of two, while acceptable arc length was maintained. FGR's increased almost linearly with voltage and with power and decreased almost linearly with current. Electrode melting rates (EMR's) displayed opposite

behavior to the FGR's in their variation with electrical conditions. EMR's increased almost linearly with current and decreased almost linearly with voltage and power. EMR's obtained using ac and dcep (dc electrode positive) were generally similar, but the EMR for electrode E-11 using dcen (dc electrode negative) was approximately 40% greater than that using dcep. In contrast to a previous referenced study, no systematic difference was observed in FGR's with ac compared with dc welding.

Fumes generated at power levels of 100A and 120A were found to have similar elemental composition with the exception of sodium and potassium, where potassium was found to be more than nine times as abundant at 120A. In general, there was a marked increase in the abundance of most elements in fume produced under low voltage conditions; however, chromium was found in lower abundance under low voltage. The chromium content in fume at 100A was found to double as the arc voltage was increased from 20 to 30V. Similar conclusions were reached by Gray and Hewitt (1982) that increasing the arc voltage reduced the hexavalent chromium content of fume from MIG welding of stainless steel.

**1.1.2 Effects of Shielding Gas.** Fume generation rates were found to be dependent on the oxidizing potential of the gas surrounding the electric arc (Malmqvist et al., 1985 and Gray and Hewitt, 1982). As the oxidizing potential of the protective gas increased, so did the fume production. Carbon dioxide in MIG welding resulted in much higher fume formation rates than argon- or helium-based shield gases used in GMAW welding. Malmqvist found the oxidizing potential of the protective gas to be as significant as welding current and voltage in the production of welding fume.

**1.1.3 Effects of Electrode Composition.** The mechanisms of fume formation have been reported by Gray et al. (1983) and Gray and Hewitt (1982). Gray et al. (1983) studied the difference between TIG, MIG, and MMA welding and investigated the mechanisms of fume formation. They studied the various sources of fume in MMA welding arising from the filler wire, flux, and workpiece and concluded that to minimize fume generation from the process, alteration of the composition of the electrode was an important factor. Welding fume fractions were defined as "flux fume", arising from the flux, and "metal fume" originating from the workpiece, filler metal, and metal powder in the flux mixture. The sources of metal fume were determined as filler wire 70 to 90%, metal powder in the flux less than 15%, and the work piece up to 10%. The flux is itself a large source of fume, and despite a low metal fume formation rate, the overall fume formation in MMA welding can be as large as for the MIG process.

Formulation changes in the composition of the filler wire and flux may reduce the fume formation rate or render the fume less toxic (Gray et al., 1983 and Gray and Hewitt, 1982). Metal added as a powder in flux makes a larger contribution to the fume than a similar weight as an alloying element in the wire. It was concluded that incorporation of the metals in the wire would result in lower exposures to the metals in the fumes (Gray and Hewitt, 1982). Gray et al. (1983) reported that flux that contains sodium or potassium silicates can introduce large amounts of hexavalent chromium when welding chromium alloys such as stainless steel. High temperature of the arc produces trivalent chromium as mixed oxide spinel. They suggested that using lithium silicate or an organic binder causes significant reduction in the hexavalent chromium in fume.

Constituents of electrode coverings were always found in welding fume, but sometimes in different percentages of an element. Concentrations of Fe, Mg, and Ca in welding fume were found in nearly identical percentages as in the covering. Fluorine, Mn, Cu, Zn and lead were found in higher concentrations in the fume and Cr and Ni in lower concentrations than in the electrode covering (Gambaretto and Rausa, 1985). Kobayashi et al. (1983) studied the relationship between the contents of elements in the coverings and in the fumes. The mechanisms of fume generation were considered, and observations were made by high speed camera. The contents of the elements in the fume increased in accordance with the increase of elements in the covering. The effects of lime type and non-lime type electrodes showed varying percentages of elemental composition and alkaline content in the fume. Iron oxide content in fumes from non-lime type electrodes was about 50%, regardless of the iron oxide content in the covering; whereas iron oxide content in the fumes from lime type electrodes did not exceed one-half that of the non-lime type. The increase in alkaline content was found to be a result of the Ca content in the covering, especially when present as  $\text{CaF}_2$ . Fume composition with non-lime type coverings is regulated by the vaporization from the molten metal surface at the tip of the electrode; that of lime type coverings is regulated by the vaporization from the molten slag surface.

The relationship between arc temperatures and fume emissions generated using covered electrodes was described by Kobayashi and Suga (1981). The presence of organic material and fluorite were found to raise arc temperature, while the presence of limestone, rutile, and alkali metals such as Li, Na, and K lowered arc temperature. Fume emissions decreased as arc temperature decreased. Considering that a reasonably direct relationship between arc temperature and fume emission rate was found, they concluded that as the arc temperature drops, so does the amount of high temperature that evaporates within the arc.

**1.1.4 Particles.** Fasiska et al. (1983) conducted a study of welding fume to provide a data base of chemical, crystallographic, and physical data for representative welding fume types to aid in the understanding of the interactions of these particles with the human respiratory system. Welding fumes from carbon steel, stainless steel, and aluminum were analyzed for particle size and chemistry by x-ray diffraction, energy dispersive x-ray analysis, scanning transmission electron microscope, and automated electron beam analysis. Particle size diameters were between 0.1 and 1.0  $\mu\text{m}$ . Less than 1% were found to be greater than 1  $\mu\text{m}$ , but STEM pictures revealed many particles as small as 0.01  $\mu\text{m}$ . There was little variation in the size distribution for the six fumes tested and little variation with the type of welding consumable or with individual particle chemistry.

The morphology of welding fume particles appeared to be spheres or clusters of spheres. No crystalline features were observed, though all particles examined produced electron diffraction patterns indicating they contained crystalline material.

If fluorides were present in the consumable, then sodium, potassium, and calcium fluorides were found in the fume. No transitional metal fluorides were detected. Silicon was found as an amorphous silica or was in solid solution with the iron oxide. The analysis of fume from an aluminum wire indicated Al present primarily as alumina with small concentrations of aluminates.

Additional scanning electron microscopic studies by Minni et al. (1984) showed the average size of welding fume of MMA of stainless steel to be 0.14  $\mu\text{m}$ , MIG of stainless steel, 0.06  $\mu\text{m}$ , and MMA of mild steel 0.12  $\mu\text{m}$ .

Minni et al. (1984) also used electron spectroscopy to analyze MMA and MIG stainless steel fume and MMA of mild steel for the oxidation states of the main metal constituents with electron spectroscopy. Following removal of the surface layers of the particles by ion sputtering, changes in the oxidation states and elemental concentrations beneath the outermost surface layer were studied. Iron in the fume of MMA welding of stainless steel exists primarily as  $\text{K}_3\text{FeF}_6$  and chromium as hexavalent  $\text{K}_2\text{CrO}_4$ . Manganese was found to occur in the oxidation states 2+ and 3+ possibly as  $\text{Mn}_3\text{O}_4$ . Iron in MIG welding fume of stainless steel was found mainly as Fe(III) in the form of  $\text{NiFe}_2\text{O}_4$  and chromium as spinels in the trivalent form as  $(\text{Fe}, \text{Ni})\text{Cr}_2\text{O}_4$ . Manganese was found in the same oxidation state as MMA of SS with the probability that it was  $\text{Mn}_3\text{O}_4$ . Nickel was present as a mixture of Ni(II) and Ni(III), together with metallic nickel possibly as NiO and  $\text{Ni}_2\text{O}_3$ , as well as Ni(II) spinels. Some particles were found to be coated apart from the normal contamination layer by a thin layer of silicon containing material. Iron in MMA welding fume

of mild steel was found as  $\text{K}_3\text{FeF}_6$  on the surface and as  $\text{MnFe}_4$  in the core of the particle.

The particle chemistry of ferrous fume was found to be dependent on the iron content of the fume (Fasiska et al., 1983). When large amounts are present, the main crystalline phase is magnetite and other transition metals exist as  $(\text{Fe}, \text{X})_3\text{O}_4$ . Only when iron concentrations are relatively low is there a possibility that pure oxides of other transition metals are present. Other oxidation states for iron may also be present, such as  $\text{K}(\text{Fe}, \text{Cr})\text{O}_4$  found in SS fume.

**1.1.5 Chromium.** An "interlaboratory/intermethod round robin" study organized by The Welding Institute and reported by Moreton et al. (1983) examined the specific problems surrounding the analysis of soluble and insoluble Cr(VI) and total chromium in fume from MIG and MMA welding of low alloy stainless steel consumables. The principal method employed was the Blakeley and Zataka s-diphenyl carbazide color method for Cr(VI), modified by using differential alkaline leaching techniques to prevent reduction of Cr(VI) to Cr(III). Total chromium was determined using atomic absorption spectrophotometry, x-ray fluorescence (XRF) or the Blakeley-Zataka method.

The participating laboratories analyzed 1 to 10 milligram bulk samples of fume collected on PVC filters of various types of fume generated by a selection of electrode types. Their results were in good agreement for the determination of the Cr(VI) soluble and insoluble species using the modified Blakeley-Zatka procedure. The Blakeley-Zatka method for total chromium, the perchloric acid fuming technique, and the AAS procedures were in good agreement for total chrome determinations. The effects of storage of the samples for periods of two weeks to three months prior to analysis for Cr(VI) indicated no significant differences in the results obtained by the participating laboratories. Similar findings for PVC filters were reported by Blomquist et al. (1983).

Blomquist et al. (1983) reported the development of filter leaching techniques that resulted in higher Cr(VI) values than the Blakeley-Zatka procedure. The use of a sodium acetate rather than sulfuric acid solution in the leaching of polyvinyl chloride filters resulted in the recovery of higher amounts of Cr(VI), together with increased stability of the solution as a function of time. The modified leaching procedure was shown to give the same results as the more laborious carbonate method. The use of Rinehart's solution to extract Cr(VI) resulted in higher values than the INCO method utilizing a basic leach, though the INCO method resulted in higher total chrome values (McIlwain and Neumeier, 1983). The techniques used to determine the Cr(VI) content of MIG and MMA stainless steel welding fume were dis-

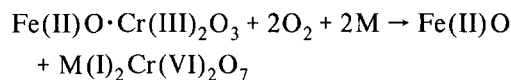


cussed by Hewitt et al. (1983) with emphasis on the need for the establishment of a correct dissolution procedure to accurately determine welding fume constituents. They indicated that hexavalent chromium can be extracted efficiently by leaching filters with a sodium hydroxide/sodium carbonate solution compared to other solvents that may give lower Cr(VI) results due to redox reactions.

Stern et al. (1984) studied the fume matrices of MMA and MIG fume and found that the water soluble fraction of CR(VI) of MMA fume is stable, while that of MIG fume is not, and that the wide range for this species reflects the extreme sensitivity of the measurements to collection, storage, and analysis techniques. Analysis of fume samples collected on standard membrane filters and those collected and fixed in impinger solutions showed wide variation. It was found that a maximum of 30% of total chromium as Cr(VI) was found when collected and directly fixed in an impinger as opposed to 3% when first collected on a filter and analyzed afterwards using standard AAS techniques. Similar findings for wide variations in the amount of CR(VI) found using impinger and filters for fume collection were also reported by Gray, Goldstone et al. (1983). The reduction effects of glass fiber and PVC filters were found to be minimal compared to that of cellulose ester filters which resulted in a 50% reduction of Cr(VI).

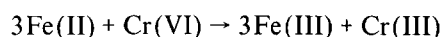
The study of the chemical evolution of hexavalent chromium in MIG and MMA stainless steel welding fume in both experimental and field conditions indicated that in the case of MIG fume, the hexavalent chromium content appears to rise to a maximum some time after formation of the aerosol, and then to partly decay again (Gray, Goldstone et al., 1983). The effects of aging of MIG fumes showed the measured ratio of hexavalent to total chromium to rise rapidly at first, reaching a maximum within 20 seconds, and then to fall reaching a steady value within a few minutes with the final value for this ratio the same as that for fume samples collected on glass fiber filters. In the case of MMA welding fume, the ratio was not found to vary significantly over the period from 1 to 90 seconds. The mechanisms of fume aging are discussed as possible explanations for the differences found between the impinger and filter collection methods. The aging mechanism is a result of physical processes such as cooling, aggregation and settling, and chemical processes described as homogeneous, involving interactions between the constituents and atmospheric gases such as oxygen; and heterogeneous, involving both fume constituents and atmospheric gases such as oxygen. Aged MIG fumes consist mostly of metal oxides and mixed metal oxides with the spinel structure such as magnetite ( $\text{Fe(II)Fe(III)}_2\text{O}_4$ ) and  $\text{Fe(II)O}\cdot\text{Cr(III)}_2\text{O}_3$  which are probably produced very rapidly at high temperature in the early stages of fume formation. After

condensation and initial cooling of the fume particles, heterogeneous oxidation could lead to formation of hexavalent chromium compounds by reactions such as:



— where M could be any one of a variety of metals present as an element or compound. Such a reaction could be inhibited by rapidly cooling the fume particle or by removing the particle from the oxidizing atmosphere, both of which could occur if the particle was collected in aqueous suspension.

Hexavalent chromium can be reduced by reaction with metals of low oxidation state, for example:



This reaction proceeds rapidly in solution, but can also occur in the solid phase at temperatures of several hundred degrees centigrade, and presumably could occur in fume particles before they finally cooled. The submicron fume particles might be expected to cool so rapidly that temperature-related aging would be unobservable. However, many of the chemical reactions that could occur in the aerosol, such as metal oxidation, are exothermic and might help to maintain a high particle temperature. Furthermore, reactions involving the solid phase can be relatively slow; proceeding at rates determined by mass-transfer processes such as diffusion of the reactive species. These possible physical and chemical processes suggest that the observed evolution of MIG welding fume could be explained by an initial rapid rise in the amount of hexavalent chromium in the fume particles as a result of oxidation reactions, and then fall as a result of homogeneous solid-phase redox reactions. In this scheme, it is envisaged that MIG fumes collected on filter papers pass through these stages on the filter, and that by the time they can be analyzed, the process is substantially complete.

This scheme could explain other properties of welding fumes. It has been found that all or most of the Cr(VI) in MIG and other welding fumes is water soluble, although the bulk of MIG fumes including chromium of other oxidation states is not. If Cr(VI) were formed by homogeneous reactions before or after fume condensation, then much of it might be expected to be found within the insoluble fume particles. If it were formed by heterogeneous oxidation reactions, then it would lie on or near the surface of the fume particles and would be more easily dissolved.

The large amount of Cr(VI) present in most fumes from stainless steel MMA welding has been shown to be associated with the sodium and potassium compounds in MMA welding fluxes, and it is almost certain that the Cr(VI) is present in such fumes as chromates of these

metals. It is possible that the stability of these compounds compared to most other metal chromates prevents or minimizes the processes leading to reduction of Cr(VI) in MIG fumes. Sodium and potassium chromates are also stable at higher temperatures than most other chromates, and this could explain the much faster formation of Cr(VI) in MMA fume than in MIG fume. If the reaction can occur at a higher temperature during the cooling of the aerosol particles, then it will commence sooner and probably proceed at a higher rate.

A second possible explanation of the observed results is that some reactive component of the aerosol, produced up to 20 seconds after fume formation, might lead to Cr(VI) formation in the presence of water. The reactive species might be a component of the fume particles or of the gas phase, for example, ozone. The eventual decline in the amount of hexavalent chromium collected in the impinger train might be the result of the decay of the reactive species, or some other property of the aerosol, such as the particle temperature. In this scheme, it is envisaged that reactions in the aerosol produce the amount of Cr(VI) found in filter samples, and an additional amount is produced by collection in water while the aerosol is in a "reactive" condition.

It should be noted that the experimental conditions of Gray, Goldstone et al. (1983) included the use of cellulose ester filters as backups to the impinger sampling trains. These filters have been found to result in lower Cr(VI) values due to the reduction effects of the filter, while glass fiber filters have shown negligible reduction effects (Blomquist et al., 1983). Thus, the observed excess of Cr(VI) in the impinger train in the Gray, Goldstone et al. study may understate the true conditions.

Stern et al. (1984) studied the distribution of metallic species into various solubility fractions and oxidation states and concluded that this is a function of the collection, fixation, and analytical procedures employed. To demonstrate this effect, impingers were used to collect fume containing various solvent mixtures which showed variations of recovery of Cr(VI) of 0 to 8% to total chrome. The observations reported raise serious questions concerning the interpretation of either positive or negative bioassay results for metals or metallic compounds as well as employee exposure determinations to the various species of chromium (Gray, Goldstone et al., 1983).

## 1.2 Gases

**1.2.1 Nitrogen Oxides.** Press and Florian (1982) reported that when shielding gas was introduced through a 16 mm diameter nozzle, nitrogen oxides generation increased with increased current in TIG welding with nitrogen oxides levels increasing above 150A and in greater proportions from 250–300A. In the presence of ozone, it was not possible to detect any nitrous oxide, but only

nitrogen dioxide; this confirmed the findings of one of two previous studies. The generation of nitrous oxide was shown to be related to nozzle diameter. Larger amounts of nitrogen oxides were formed with smaller nozzles as compared with nozzles of larger diameter. The increase was attributed to the turbulent mixing between the stream of shielding gas and the ambient air due to the high exit velocity of the shielding gas from the smaller nozzles.

**1.2.2 Ozone.** Factors that affect the production of ozone in TIG welding, such as arc voltage (length of arc), and parameters relating to the shielding gas were also reported by Press and Florian (1982). Ozone concentrations were found to increase with current to approximately 175A and drop with increasing current, a result of the increased concentrations of nitrogen oxides generated above 150A. The increased nitrogen oxide production in TIG welding is a result of the shielding gas's inability to screen off the longer arc from the surrounding air. At 250–300A, the concentrations of ozone were found to be very small due to the increased generation of nitrogen oxides. Increases in voltage with increasing arc length resulted in higher levels of nitrogen oxides and lower levels of ozone.

Ozone levels were found to be higher with increased flow of shielding gas due to the reduction in the amount of nitrogen oxides produced. Concentrations of ozone were also found to be much lower when the rate of flow of shielding gas was reduced to below that normally used in welding operations. It was concluded that low levels of ozone can be achieved by using the smallest amount of shielding gas possible.

Fouling of the nozzle with spatter which created more turbulence and mixing of ambient air resulted in increased nitrogen oxide levels and lower levels of ozone. The effects of different size nozzle diameters when used with identical shield gas flow rates indicated varying concentrations of ozone. Smaller diameter nozzles which create more turbulence resulted in lower levels of ozone when compared to larger nozzles producing less turbulence.

Using various proportions of hydrogen and helium as compared to pure argon is known to affect arc characteristics. No conclusions were reached as to whether ozone levels can be reduced by using various inert gas mixtures in the shielding gas. However, the introduction of nitrogen oxides to the shielding gas was found to appreciably reduce ozone levels while negligibly increasing the nitrogen oxides levels.

Testing was conducted on the effects of increased air turbulence by blowing air onto the gas shield. It was shown that as the rate of flow increased so did the levels of nitrogen oxides with subsequent reduction of ozone levels. The results of testing nozzles designed to create turbulence in the outer layers of the shield envelope were promising and will require further investigative work.

Levels of ozone generated during GMA welding of Cu-Ni and Ni-Al bronze (NAB) alloys and ozone control measures were reported by Ditschun et al. (1983). Concentrations of ozone using both alloys indicated higher concentrations of ozone with increasing voltage (26 to 29 V) by factors up to four; and decreasing current. The effects of the incorporation of helium in the argon shielding gas indicated suppressed ozone production. However, the effects were overridden with increasing voltage, which caused the ozone levels to increase significantly. Various types of opaque arc shrouds positioned closely around the welding arc or crossdrafts sufficiently strong to remove ozonated air were found to dramatically reduce ozone levels. The use of shrouds reduced ozone concentrations at given points by factors of greater than 5 to 10. Faggetter et al. (1983) reported suppression of ozone levels using stainless steel mesh shrouds and ventilation shielding cabinets in GMAW welding of aluminum with reduction in exposure to levels well within the ACGIH TLV.

Downey et al. (1983) compared ozone measurements made with the conventional NIOSH Method [sampling with impingers containing alkaline potassium iodide (AKI) followed by colorimetric analysis] with measurements made with a direct-reading chemiluminescent monitor. They found that both methods were acceptably accurate and precise when tested with known pure ozone concentrations in the laboratory. When measuring ozone concentrations from MIG welding, however, the AKI method gave much lower results than the direct-reading instrument. For sample periods less than 10 minutes, the AKI results were only 10 to 15% of those found from the direct device. For a longer sampling period (44 minutes), the AKI results were closer to, but still substantially less than, those of the direct device, falling in the 53 to 62% range. The authors suggest that previous measurements made with the AKI method probably under-represent true ozone exposures of welders.

### 1.3 Electromagnetic Radiation

**1.3.1 Ultraviolet Radiation.** Measurements of ultraviolet (UV) radiation from MIG (GMAW) welding arcs were made by Eriksen (1985). The use of a Diode Array Rapidused Scan Spectrometer indicated that an overshoot of radiation can occur during the first 50 ms of arc ignition. At 280 nm, the UV irradiance can overshoot (by more than 10 times) the steady state average value. It was implied that the effective UV dose can be reached with one single ignition at 300A for an unprotected eye at a distance of 0.5 m. Tack welders and nearby assistants should use eye protection for any welding arc exposure.

**1.4 Noise.** The effects of various welding parameters on the equivalent continuous sound levels was studied by Eichbauer and Schmidt (1982). In MMA welding,

neither the thickness of the workpiece, the form of the weld, nor operators' welding positions had any effect on the continuous sound level measured. The sound level was found to increase with current during the welding of a root pass. During the welding of the final pass, the continuous sound level was found to be slightly lower than that for the root pass. At some point, a slight decrease in the continuous sound levels were found with increasing current. The continuous sound levels were found to be between 70 and 80 dB(A).

Studies of gas welding showed that all welding parameters had an effect on the increase of continuous noise levels. Flames fitted with blowpipes were approximately 15 dB(A) quieter than those not so fitted. Increases in continuous noise levels were found with increasing nozzle diameters and rates of gas flow.

Continuous noise levels during GMAW welding were found to increase during the welding of thin-gauge sheets and decrease on thick-gauge plates as current increased. MIG welding of thin-gauge sheets also indicated increased continuous noise levels with increasing current. The continuous noise level of MAG welding of thin-gauge sheets was approximately 80 to 93 dB(A) and thick-gauge sheets between 75 and 87 dB(A). MIG welding of thin-gauged sheets indicated continuous noise levels of 87 to 97 dB(A).

Octave band analysis of welding noise was used for the evaluation of subjectively perceived loudness of various welding processes. MIG welding was perceived to be twice as loud as TIG welding.

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## 2. Investigations in Humans

**2.1 Diseases of the Respiratory System.** A very thorough evaluation of pulmonary function in welders (mis-labeled a case control study) was carried out by McMillan and Pethybridge (1984). The investigators invited all 368 welders employed at Her Majesty's dockyards in Devonport, Portsmouth, and Chatham in England to have clinical examinations, pulmonary function tests, and full-sized posterior and anterior chest x-rays. Of the 328 (89.13%) who participated, a random sample of 135 of these volunteers selected from the welders aged 45 years and over formed the exposed group in the analysis. (The authors do not indicate denominators for all volunteers 45 years and over or all welders 45 years and over.) The number of exposed welders was limited to 135 because of time and funds constraints. Each of the exposed was individually matched — on sex, smoking habit, age to one year, and an estimate of the potential to asbestos dust, with a skilled craftsman employed in the yard who had never been a welder but, because of his skill, was considered similar in social class. Unfortunately, the matching was not retained in the analysis, resulting in a decrease in efficiency. An interview based on a standard questionnaire and a clinical examination were conducted. Spirometry was carried out, including forced expiratory volume in 1 second, forced vital capacity, and residual volume. Chest x-rays were read blindly by three expert readers, with a consensus of at least two being needed to score the x-ray for pleural fibrosis, secondary to asbestos exposure and small, regular opacities.

\*Complete documentation not available — need additional information.

The welders had been welding for an average of 33 years. All the men had been employed on manual metal arc welding, usually of mild steel, but a few had done more metal inert gas welding or tungsten inert gas welding. The proportions of welders and controls who gave a history of having pleurisy, tuberculosis, bronchitis, or pneumonia were similar in the welders and controls, although one wishes that only the discordant pairs had been reported because a true association may have been missed through large numbers of concordant pairs. In both the welders and the controls, the period prevalence of all respiratory disease was much higher in smokers and exsmokers than in nonsmokers, a finding suggesting that an association that strong would be seen even within the limitations of the authors analysis.

The proportion of the 135 welders reporting most respiratory and cardiovascular symptoms was similar to that in the 135 controls. The proportion of welders was somewhat higher for chronic cough (defined as a cough on most mornings for at least three consecutive months of the year for two years or more) and hemoptysis (coughing up blood). There was a marked difference regarding dyspnea (shortness of breath), which was reported by nearly four times as many welders as controls. Physical examinations revealed that approximately twice as many controls as welders had rales (abnormal sounds at the base of the lung), but the number in each group with another type of abnormal sound known as rhonchi was similar. Without further information, interpretation of the clinical significance of these findings is difficult.

With regard to the chest x-rays, one reader diagnosed nearly twice the number of small opacities as did the other two readers who were in excellent agreement. However, even that one reader found approximately 6% with small opacities, so that in reality, the overall agreement was quite good. According to the authors, all these abnormalities occurred in either present or former smokers. Although the data were not presented, the authors stated that there was virtually complete agreement among the readers regarding presence or absence of pleural fibrosis. Thirty-five of the welders and only nineteen of the controls had pleural fibrosis, with the difference being statistically significant in present smokers.

According to the spirometry, approximately twice as many welders as controls had mixed obstructive and restrictive respiratory disease with the differences being greater among the exsmokers and nonsmokers. There was slightly more pure restrictive disease among the welders and slightly more pure obstructive disease among the controls. However, among the 23 nonsmokers in each category, 6 of the welders and none of the controls had pure obstructive disease.

With regard to specific pulmonary function tests, the forced expiratory volume in 1 second decreased faster

with age among welders, although this difference was not statistically significant. Residual volume also increased over time faster in welders than in controls. The total lung capacity in welders decreased more slowly with increasing age than in controls.

In summary, the authors found only a few differences between welders and controls and surprisingly little disease, considering how long the individuals had been working. Welders did have a substantially higher prevalence of dyspnea and of mixed (in terms of restrictive and obstructive) pulmonary disease. However, the higher prevalence of pleural plaques in the welders suggested to the authors that the welders apparently had higher asbestos exposure than did the controls, and this could have explained the differences found. Only four of the welders had "radiographic evidence consistent with the diagnosis of siderosis", which also suggests that the differences found are due to asbestos exposure rather than welding fume. An earlier study by McMillan and Pethybridge (1983) also suggested that it is difficult to study the effect of welding fume in shipyard welders because there was a clear gradient of mesothelioma and asbestosis with welding fume exposure. This suggests that welders, within these shipyards at least, were more heavily exposed to asbestos than the other shipyard workers.

In spite of the fact that the authors did not recognize the correct category into which their epidemiologic study fell, this is a reasonably well-conducted and well-interpreted study. The only flaw is the failure to take the matching into account in the analysis, with the result that correct relative risk estimates cannot be made and efficiency is lost. If the authors have retained their raw data, there is still an opportunity to have the data reanalyzed properly, taking into account the effect of matching.

Because McMillan and Pethybridge (1984) were unable to eliminate the confounding effect of asbestos exposure in such an otherwise well-designed study in shipyard welders, it is indeed welcome that Waddington et al. (1983) have announced that a clinical study is planned to define acute and chronic effects of welding on the respiratory system, with special respect to exposure to hexavalent chromium and nickel and stainless steel welding fumes. Waddington et al. are also planning to use mild-steel welders as well as nonwelding cohorts as internal controls and apparently are also proposing external controls. The exposed cohort will comprise a minimum of 500 stainless steel welders employed during 1960 or earlier, with particular emphasis on finding the welders employed during 1950 or earlier. The mild-steel welding cohort is proposed to be larger, but numbers are not stated. Because part of this study, assessment of current exposure to welding fumes will be based on chemical analysis of fumes collected on filters for iron, total chromium, total and water-soluble hexavalent

chromium, and total and acid soluble nickel, the authors also proposed to obtain a lifetime history of occupational exposure to welding fumes and to hexavalent chromium by means of a questionnaire emphasizing welding methods, relative ranks of exposure, use of electrodes or rods, types of steel, and use of primers and coatings. They also propose, through the analysis of blood and urine, to evaluate and validate the methods of assessment of current chromium and nickel exposure in the welders. They will use an informal questionnaire to determine current health status of welders, with particular emphasis not only on chronic bronchitis but also on dermatitis and metal fume fever. Pulmonary function assessment will include at least forced vital capacity, forced expiratory volume in 1 minute, the ratio of forced expiratory volume to forced vital capacity and FEF<sub>25-75</sub> and FEF<sub>75-75</sub>, with additional pulmonary function tests likely as well. They are also planning to carry out sputum cytology on the subjects. The results of this study, if it is carried out as planned, should be of great interest.

McMillan (1983) summarized all the shipyard welding studies but did not discuss the methods or present the results in detail. Fortunately, almost all of the discussion in this paper summarizes work of papers that have been reviewed in detail either in this report or in its predecessors. However, a small amount of the discussion in this paper (McMillan, 1983) has not appeared elsewhere and will be discussed here. As described earlier in this section, there were 328 participating welders. Of these 328, 18 were diagnosed as having the pneumoconiosis, siderosis. According to McMillan, "in the 18 men with siderosis, there was no constant relationship between radiographic abnormality and length of employment as a welder, clinical abnormality of the chest, or lung function impairment". McMillan interpreted the results as showing low exposure to welding fumes among the dockyard welders, but in this summary paper there is insufficient information to determine the correctness of the interpretation.

Also according to McMillan (1983), "a high (otherwise unspecified) proportion of the welders had suffered from metal fume fever, usually due to welding on galvanized surfaces." Because McMillan (1983) also reported frequent eye injuries and burns and little use of protective equipment, the metal fume fever may also have resulted from inadequate work-protection practices, as McMillan implies in the summary.

McMillan (1985) recently presented a paper about risk of death from respiratory disease among welders by type of exposure. Unfortunately, only an abstract is available for review, and a full discussion of the study will need to await publication of the entire proceedings. McMillan discusses the fact that the Registrar General for England and Wales had published decennial supplements of occu-

pational mortality, which had been frequently quoted by those arguing that welders were at special risk of death from respiratory disease. During the period 1970 to 1972, there were 149 deaths from pneumonia, bronchitis, emphysema, or asthma among the Registrar General's grouping, gas and electric welders, steel cutters, and braziers. Twelve of these were in burners or cutters, who — as McMillan points out — have different exposures. However, they make up only about 8% of the deaths; therefore, even if their mortality experience is different, it should not affect the results very much. Since potential health hazards can vary dramatically from one welding process to another, it is unfortunate that only 39 of the 137 death certificates for the welders gave any indication of the process. (This abstract also supports the need for the studies proposed by Waddington and colleagues.) McMillan then goes on to state appropriately that the Registrar General's statistics should be thought of as generating hypotheses rather than testing them.

At the same symposium, Newhouse et al. (1985) reported on mortality of mild-steel welders at a shipyard in northeast England. According to the abstract, which is all that was available for this review, the welders showed an excess mortality from pneumonia, but the magnitude of the SMR was not given.

In a study available for review only as an abstract, Mur et al. (1985) conducted surveys on the pulmonary function of welders from one electromechanical plant and two factories producing industrial vehicles. A total of 536 welders from the three plants and 558 controls from the same plants were given a standard bronchitis questionnaire, a clinical examination, chest radiography, and the following pulmonary function tests: flow-volume curves taken before and after acetylcholine-induced bronchial constriction, carbon monoxide lung transport tests by the single-breath and steady-state methods, and an N<sub>2</sub> washout test.

Bronchitis and some specific radiological abnormalities such as nonsiderotic reticulomicronodules occurred slightly more often, but not significantly more often (statistics not reported), in welders than in controls. No significant differences were observed in any of the pulmonary function tests between welders and controls except the carbon monoxide transport test. Pulmonary transport of carbon monoxide was significantly impaired (statistics not reported) among welders, especially welders who were smokers. Based on these results, the authors requested that the carbon monoxide transport test be used to monitor pulmonary function in welders.

A brief report of a cross-sectional study of welders from East Germany was published in English (Schneider et al., 1981). Perhaps because the paper is only two pages long, there are not enough details on the methodology to know whether the controls were selected appropriately. A

higher proportion of the welders complained of “dryness of the upper airways” and chronic sputum production within each category of nonsmokers, exsmokers, and present smokers. According to the authors, there were no differences in pulmonary function tests between welders and controls, although the specific results were not presented. However, in the absence of information on the quality of the study design, no conclusions can be made.

Fawer et al. (1982) carried out a small-scale investigation of absences due to sickness among all 50 welders who had worked between January 1, 1970, and December 31, 1979, in a petrochemical plant. Fourteen were excluded from the study, thirteen because they had worked less than one year or because of insufficient information. The remaining 36 welders were compared with 36 controls from the same social class within the same plant. Each control was individually matched by date of birth (within five years), duration of employment during that decade, date of hire (within three years), degree of fitness at the pre-employment examination (not specified otherwise), and smoking habits (apparently only in terms of whether they were nonsmokers, former smokers, or present smokers). Unfortunately, the study is weakened because after going to all the trouble to match controls individually, the authors ignored matching in the analysis. This is unfortunate because the authors handled the often tricky problems of study design reasonably well. The controls are selected much better than is usually the case, and the problems with ascertainment of sickness absence were well handled as follows. Although diagnoses for sickness absences are not systematically validated, each employee is reviewed by the company medical center if they are absent for more than three days. The authors therefore confined their analysis to absences of more than three days for illness.

For all illnesses combined, the average number of days sick, average length of each individual illness absence (by definition, over three days), the total number of spells, and the proportion of workers having one or more new spells were each similar in the welders and the controls. However, for respiratory diseases, the average number of sick days for welders was 2.5 times that of the controls and the total number of new spells was 80% higher for the welders. The average length of the spell was about 40% longer for the welders, and the proportion of workers with one or more new spells was 28% higher among the welders. When the respiratory diseases were divided into upper and lower respiratory tract, different trends emerged. For the average number of new spells and the proportion of workers with more than one spell, very little difference between the welders and the controls was seen for upper respiratory tract diseases. For lower respiratory tract diseases, however, the rate of new spells was 5 times as high and the proportion of workers with

more than one spell was approximately 2.5 times as high among welders. For the average number of sick days lost, the trend in difference between welders and controls was more marked for lower respiratory tract diseases, but was nearly twice as large for the upper respiratory tract diseases as well. For the average duration of a particular sickness absence, the only differences seen were for upper respiratory tract diseases, with the welders' absences being an average of over 40% longer. For lower respiratory tract diseases, an interaction was seen with smoking, with the differences between welders and controls — at least in terms of average duration of each absence and the proportion of employees with one or more new absences — being more striking for smokers in welders than in the controls. Surprisingly, the smokers among the controls had slightly better indices than the nonsmokers. This may indicate that the smokers among the controls were younger, because smokers were not matched to nonsmokers, or it may indicate that the smokers in the controls were relatively light smokers. If the latter were true, it would be hard to interpret the greater differences between welders and controls seen in these statistics among smokers; in that hypothetical situation, the welders might be heavier smokers. In any event, since the nonsmokers are comparable in the amount smoked and are matched, and therefore comparable on other factors (even though the matching was not properly handled in the analysis), the differences between welders and controls cannot be explained solely by smoking habits.

Although the authors presented no data, they stated that there were no differences between welders and controls in absences attributed to digestive diseases. Digestive diseases were analyzed because they were thought to be unrelated to welding exposures and would be an indicator of bias in ascertaining sickness absence unrelated to welding exposures.

In spite of the less-than-perfect analysis, the good design of the study and the magnitudes of the differences indicate that welders are more likely to be absent because of respiratory diseases, particularly lower respiratory diseases, and to be absent longer from work with these conditions than similar workers — at least in the company studies (to the extent that the relatively small numbers permit generalization). It is not clear how clinically significant these increased absences are in terms of long-range health effects. The authors did note four absences from pneumonia in the welders and none in the controls and pointed out that earlier investigations reviewed in earlier editions of the *Effects of Welding on Health* had found elevated SMRs for pneumonia in welders. The authors specifically note that even though they were able to control for social class, age, smoking habits (at least in terms of present, former, and non-

smokers), and duration of employment, the results might have been influenced by other factors not controlled in the study; e.g., attitude of supervisors, personality of the worker, and job satisfaction. The authors also point out that the welders may consider themselves at higher risk of respiratory disease, and this belief may influence not only their behavior but also their physician's diagnosis.

There remains another finding implied in the results presented by Fawer et al. (1982). For all diseases — other than respiratory — combined, the welders apparently have fewer absences and shorter absences than the controls; otherwise, the welders would have an excess in these indices for all absences. This is shown by the finding that 56% of the days lost in welders and 24% of the days lost in the controls were due to respiratory diseases, and 65% of the absences in the welders and 40% of the absences in the controls were due to respiratory diseases. Therefore, even in the controls, respiratory diseases made up a large enough proportion of the sick days absences that something had to compensate for the similarity of findings in welders and controls for all sick days and sick absences. This could mean that the controls are at increased risk for other diseases, or it could mean that the welders are in general healthier than the controls, in which case the absences pattern for respiratory diseases is even more striking.

In summary, at least in this facility, Fawer et al. have shown that for respiratory disease alone, and primarily lower respiratory disease, welders have more sick days, more sick absences, and greater severity in terms of number of days absent from work for each sickness absence than do comparable workers. Although the immediate clinical consequences of this finding are clear, the long-range implication for the welders' health is unclear from this study alone.

In a study published so far only as an abstract, Di Maria et al. (1984) examined 139 white male workers (those who had been exposed for at least five years) of 169 white male workers at a metal factory where electric arc welding was a common practice. However, nine subjects were excluded because they were unable to produce satisfactory pulmonary function tests. Thirty-seven male employees were included as controls, but the abstract does not state how the controls were selected, so comparability of controls with the exposed individuals is not clear. The authors obtained pulmonary function tests and applied a questionnaire, presumably the Medical Research Council standardized questionnaire on respiratory diseases (but the abstract does not so state). Smokers and nonsmokers were analyzed separately. The exposed workers, including the welders, had an average of 14 pack years among their smokers in comparison with an average of 10.6 pack years among the smoking controls. This suggests that the two groups of smokers

were not comparable. Among the nonsmokers, only the exposed group had symptoms of cough, sputum, and a history compatible with the standard definition of chronic bronchitis. In the smokers, the controls were more likely to report cough, but the sputum-production history and chronic-bronchitis-symptom history had a higher prevalence among the smoking welders. In both smokers and nonsmokers, the welders were more likely to have reduced Forced Expiratory Volume<sub>1</sub>, but the controls were more likely to have a reduced Maximum Expiratory Flow<sub>75</sub>. In both welders and controls, as might be expected, the smokers were more likely to have respiratory symptoms and abnormal pulmonary function tests. The interpretation of this study will have to await publication of a full report because the comparability of the controls cannot be evaluated from the abstract.

Keimig et al. (1983) reported the results of a cross-sectional study that was particularly designed to examine mild-steel welders without asbestos exposure. The investigation was carried out in a John Deere factory that manufactured bulldozers, road graders, and heavy construction equipment of other types. The plant consisted of a series of interconnected buildings, which housed different parts of the production process. In two of these buildings, gas metal arc welding and flux cored arc welding on mild steel were carried out by welders who were not concurrently exposed to asbestos. The controls were hourly paid workers in other buildings who had minimal exposure to known respiratory irritants and who had never been employed as welders. The participants were white males between the ages of 25 and 49 who had been employed at the plant for at least four years, who were employed on the first shift at the time of the study, and who had minimal past employment in foundry, diesel, or solvent fume exposure type jobs. Nonsmokers who had smoked less than 20 packs of cigarettes or 12 ounces of tobacco in a lifetime and had never smoked more than one cigar a week for one year were compared separately from smokers who were defined as smoking at least one cigarette per day for one month before the pulmonary testing. Mean ages of welders and controls were comparable, as were mean weights except for the welders who smoked, who were over 10 pounds lighter than all other groups, including the nonsmoking welders. The welders were an average of approximately 1.5 inches shorter than the controls, among both the nonsmokers and the smokers. The controls had been employed an average of one to two years longer at the plant, and the welders had an average of approximately nine years of welding exposure. Among the smokers, the controls had approximately 25% more pack years of smoking.

Welders and controls were scheduled for questionnaire and examination together throughout each week to



avoid the possibility of any daily or weekly variability in pulmonary function measurements. On their scheduled day, participants reported to the pulmonary testing site at the beginning of the first shift, before any workplace exposures. A standardized, self-administered American Thoracic Society questionnaire was completed before pulmonary testing, which included Forced Vital Capacity, Forced Expiratory Volume, and Forced Expiratory Flow measurements taken by one investigator on one pulmonary function instrument, under standard conditions.

The study population consisted of 46 nonsmoking welders, 45 smoking welders, 35 nonsmoking controls, and 45 smoking controls. No welder had welded more than 214 months. Twenty-two of the ninety-one welders had welded outside of the plant; according to the authors, they had primarily been production manual arc welders of mild steel in apprenticeship programs in small manufacturing companies. Fifty-five of the controls were employed in machining departments, eighteen in assembly departments, and seven in shipping departments.

The authors presented questionnaire results for cough, sputum, number of episodes of cough or sputum, wheezing with colds and without colds, shortness of breath, whether colds went to the chest, and history of bronchitis, pneumonia, and asthma. Among both welders and controls, smokers had a higher prevalence of respiratory symptoms or history of disease with one exception: there was considerably less asthma among smokers than nonsmokers. Cough sputum were more frequent in the welders in both smokers and nonsmokers. The number of episodes of cough or sputum and wheezing with a cold were more prevalent in welders among the nonsmokers, with essentially no difference between welders and controls among the smokers. Several symptoms or disease histories, including wheezing in the absence of a cold, whether colds went to the chest, and a history of bronchitis, were more prevalent among welders in nonsmokers and more prevalent among the controls in the smokers. (As noted above, the smoking controls smoked more pack-years than the smoking welders.) Welders who smoked, reported a higher prevalence of pneumonia than did control smokers, but the results for the nonsmokers were very similar for welders and controls. Essentially no difference was seen for prevalence of shortness of breath symptoms or asthma; if anything, these were more prevalent among the controls.

For the pulmonary function testing, the authors unfortunately only reported mean values. As is well known to epidemiologists (see, for example, the discussion on page 267 of MacMahon and Pugh, 1970) a comparison of distributions gives a clearer picture of risk associated with an exposure than does a comparison in terms of means or other summary statistics. For the Forced Expiratory Flow statistics, the means for the

welders are consistently lower (by 3 to 7%) than for the controls — both for smokers and nonsmokers. Reporting these findings as means may obscure a substantial difference in risk, but without the distributions, we do not know whether this is the case. For Forced Vital Capacity, the welders had lower values than the controls among the nonsmokers but higher values than the controls for the smokers. In fact, the smoking welders had higher values than the nonsmoking welders and means that were practically identical to the corresponding means for the nonsmoking controls. For Forced Expiratory Volume<sub>1</sub>, the means for the welders were lower among the nonsmokers but were higher than the means for the controls among the smokers who (as noted above) had greater average pack-years. Once again, for both of these pulmonary function tests, because distributions were not given, it is not clear whether the small differences seen reflect substantial differences or virtually no differences in risk.

The authors point out that the lower pulmonary function measurements in welders relative to controls might be interpreted as a true welding effect that was observed, perhaps because the individuals most susceptible to the irritating effects of welding fumes could have transferred to other jobs, leaving less susceptible welders to be studied, or because the welding exposures, which were relatively short, may have been too brief for the effects to show up. On the other hand, the authors note that their results are compatible with welding exposures not being associated with any pulmonary impairment. It is indeed unfortunate that they did not present distributions, which would help resolve these two possibilities. As the authors note, their results are equivocal, probably because of the way that the data are presented. Differences in the peripheral airway measurements could be trivial or they could represent the initial and possibly reversible stages of chronic obstructive pulmonary disease. The authors suggest that long-term follow-up provided by a large cohort study would be needed. Such a study of course could determine the fate of welders who left employment. Several such studies were reviewed in *Effects of Welding on Health IV*, and if there were an increased risk of respiratory diseases from welding, increased risk of death from respiratory diseases, emphysema, or other chronic respiratory diseases they would have been noted in these studies. The absence of such increased risks could be taken as evidence that there are no serious long-term respiratory health effects from welding.

In general, the Keimig et al. (1983) study is well designed, particularly in terms of control selection, but the data are presented in such a way that the results are difficult to interpret. The authors themselves have noted that cohort studies offer better means of answering the question of whether there are serious health effects from

respiratory diseases as a result of welding exposure. Because these studies have already been done and were reviewed previously, their findings, if the studies were designed properly, should be taken as the best indicators of whether there is increased risk of serious respiratory disease from welding exposures.

Lyngenbo et al. (1985) examined pulmonary function and respiratory symptoms in highly exposed Danish electric arc mild-steel welders, but this is only available as an abstract for this review. After 74 nonsmoking welders and 31 matched controls completed the Medical Research Council standardized questionnaire on respiratory symptoms, the welders had a statistically significant ( $p = 0.001$ ) higher prevalence of upper respiratory symptoms, such as colds, hoarseness, and inflammation of the throat, and lower respiratory symptoms, such as cough, chronic bronchitis, dyspnea, and wheezing. The abstract provides no information on how much higher the prevalence was in welders or how the controls were matched. According to the authors, a dose-effect relationship between welding fume exposure and upper respiratory symptoms was observed. The lung function tests showed that the welders have a statistically significant reduced TLC (total lung capacity), VC (vital capacity) ( $p = 0.008$ ), FEV1 (forced expiratory volume in 1 second) ( $p = 0.025$ ), FVC (forced vital capacity) ( $p = 0.001$ ), PEF ( $p = 0.0013$ ), MEF75 ( $p = 0.03$ ), TCO ( $p = 0.02$ ), and slope of alveolar plateau ( $p = 0.02$ ). No information on the magnitude of the decrease was provided in the abstract. The investigators concluded that welding fumes bring about upper and lower respiratory symptoms and reduced lung function parameters. Evaluation of this investigation cannot be made until the full account of the methods and results is available.

Kalliomäki et al. (1982) investigated respiratory symptoms and pulmonary function of manual metal arc (MMA) stainless steel welders. The authors noted that although MMA welders of mild steel had been extensively investigated, there had been very little reported on investigations of respiratory effects of stainless steel MMA welders. Because the fume emission of the MMA process is much higher than that of the tungsten inert gas (TIG) process (at least 100 times as high), the authors felt that stainless steel TIG welders could be, in effect, a nonexposed comparison group. The authors investigated 83 stainless steel welders from a shipyard with minimal exposure to mild steel welding fumes and other industrial metal aerosols (MMA mild-steel welding approximately 11% of their work time during the last 10 years, according to the authors) who have been welding stainless steel for at least 5 years. They also investigated 20 mild-steel MMA welders from one of the shipyards, presumably one of those from which they had obtained some stainless steel welders. The stainless steel welders

were divided into four groups according to the percent of time spent on MMA welding, with the remainder of the time being spent on tungsten inert gas welding. Apparently (the word “apparently” is used frequently in this description because the descriptions are less complete than ideal and are occasionally ambiguous), the percentages of time that the four groups spent on MMA are as follows: first group of 20, less than 10% (average of 3%); second group of 16, 11 to 40% (average of 30%); third group of 18, 50 to 79% (assuming a typographical error in the table) (average of 58% approximately); and fourth group of 29, over 80% (average 96%). In one shipyard, presumably one of several shipyards from which data on stainless steel welders were obtained, 29 mild-steel welders were also investigated. Apparently, this was done because the authors wanted to directly compare stainless-steel MMA welding with mild-steel MMA welding using the same methods. In comparing the groups on other parameters, the proportion of smokers was higher in the stainless steel manual arc welders greater than 80% MMA and the 11 to 40% MMA stainless steel welders with the proportion of smokers being lowest in the 50 to 79% MMA in stainless steel welding group. Regarding mean ages, all that the authors presented was that the 50 to 79% MMA stainless steel welders were somewhat younger and the greater-than-80% stainless steel welders, and particularly the mild-steel welders, were somewhat older than the other welders studied. The mean duration of exposure was somewhat shorter for the two groups with 11 to 79% MMA and was considerably longer for the greater-than-80% MMA and for the mild steel welders. In making their comparisons, the authors apparently did not adjust for age and exposure differences but did attempt to measure the smoking parameter in an unspecified manner, but presumably by comparing the nonsmokers with the smokers regardless of amount smoked.

Data collected included the Medical Research Council standard questionnaire on chronic bronchitis, a detailed questionnaire (otherwise unspecified) on subjective respiratory symptoms “associated with welding”, and a detailed occupational history. Pulmonary function tests included maximum expiratory flow, forced expiratory volume in 1 second, maximum expiratory flow at 50% and 25% of the forced vital capacity, and the closing volume. The authors apparently regressed these data against the MMA welding in the stainless steel welders, using each of the four groups as a separate data point. The slope of the regression line was used to estimate the effect of the MMA welding exposure. The effect of smoking apparently was estimated by comparing smokers with nonsmokers, but other than stating that the effect of smoking was determined, the authors provided no information on how it was done.

Dust retained in the lungs increased with increasing percentage of time spent in MMA welding among the stainless steel welders. The mean amount of lung dust was approximately 20 times as high in the over-80% group than for the less-than-10% group. Interestingly, this value for the over-80% group among the stainless steel welders was approximately 4 times that seen in the mild steel welders. Urinary chromium concentration increased among the stainless steel welders with increasing proportion of time spent in MMA welding, particularly for the over 80% MMA group which had a urinary chromium concentration approximately 6.5 times that of the less than 10% MMA group. Cough, sputum, grade 2-4 dyspnea, and chronic bronchitis increased with increasing proportion at times spent on manual metal arc welding. According to the figures provided by the authors, the magnitude of these effects was similar to the magnitude of the effect of smoking. For irritation of the upper respiratory tract and attacks of dyspnea associated with welding, determined as subjective symptoms, the increase with increased time spent on MMA welding was considerably more marked than the effect of smoking. In fact, attacks of dyspnea associated with welding decreased with smoking. Among pulmonary functions, vital capacity, forced expiratory volume, and maximum expiratory flow decreased with increasing MMA welding exposure and with smoking. The effects of the welding exposure were comparable to or slightly greater than the effects of smoking. The increase in closing volume difference was more marked in smoking than the corresponding increase with increased MMA welding. According to the authors, the prevalence of symptoms of chronic bronchitis was dependent only on smoking; the most prevalent symptom was chronic rhinitis. Although the mean vital capacity of all groups was within normal limits, it decreased faster than predicted as a function of exposure time. The estimated effects of welding exposure, as determined by the authors, seem to be more marked in the mild-steel than in the stainless steel welders.

The authors concluded that welders cannot be considered a homogenous group in respect to exposure and possible associated health hazards. They specifically concluded, as implied above, that the pulmonary function of the mild-steel MMA welders was more seriously affected than that of the stainless-steel welders. They also noted that "according to our preliminary study," pulmonary function tests indicate that pathological changes occur mainly in the peripheral airways and alveoli. The pollutants from welding mainly accumulated in the lower parts of respiratory organs. They noted that it is now recognized that vital capacity forced expiratory volume in 1 second, percentage of forced expiratory volume in 1 second, and percentage of forced vital capacity are not sensitive enough to detect changes in small

peripheral airways. They suggested that results of previous spirometric studies that compared welders and comparison groups "conflicted" because these indices were not sensitive enough.

The most common symptoms of vanadium pentoxide exposure are respiratory tract irritation (i.e., coughing, wheezing), chest pain or discomfort, dyspnea, and eye and throat irritation. These health problems occurred in at least 74/100 (all who could be examined) boiler-makers (mainly welders) who were exposed to high levels (0.05 to 5.3 mg/m<sup>3</sup>) of vanadium pentoxide (a volatile fuel oil constituent) fumes during an oil-to-coal conversion at a Massachusetts utility power plant company (Levy et al., 1984). The vanadium pentoxide levels measured in the air samples were at or above the OSHA permissible exposure limit (PEL) of 0.05 mg/m<sup>3</sup>, though chromium, nickel, copper, and iron oxide fumes were within acceptable limits. The most frequent symptom reported from the questionnaire survey was a cough with sputum (85%); wheezing was the most frequent sign found during the physical examination. Mild hypoxemia was noted in several workers. The chest x-rays were normal for 72 of the subjects. The pulmonary function tests revealed that FVC was 87%, FEV1 was 93% of predicted value, FEV1/FVC was 79%, and the expiratory flow rate over the middle 50% of the forced vital capacity was the most affected (median, 57% of predicted).

Limitations of the study recognized by the authors included: (1) it relied on self-administered questionnaires; (2) its inability to obtain health status of 26 workers; (3) clinical and laboratory information was obtained from various sources and so may not have been comparable; and (4) the investigation was performed after exposure had ceased.

El-Gamal et al. (1985), in a presentation at a symposium reported only as an abstract, determined the relative sensitivities of single breath nitrogen and flow volume indices as methods for detection of early respiratory impairments in young men. Five hundred thirteen young shipyard workers (aged 18 to 47 years) were examined, and the following tests were administered: anthropometry, ventilatory capacity, flow-volume curves, closing volume and Fowler nitrogen test, and respiratory unspecified and occupational questionnaires. The shipyard workers were divided into three categories: welders, caulker/burners, and other tradesmen. According to the authors, occupational fumes were directly related to deterioration of lung function and accentuated the effects of age and smoking. In this study, the single-breath nitrogen test (including closing volume) was more discriminatory than the flow-volume curve. It was unclear from the abstract which group of workers the investigators were referring to when discussing the results.

A follow-up study of 47 shipyard arc welders from 1976 to 1982 was presented by Kalliomaki et al. (1985) in the same symposium, so only the abstract was available. Though this six year follow-up period was too short to examine changes in the lung function parameters, preliminary tests performed included spirometry, closing volume, the carbon monoxide transfer factor, and magnetopneumography. The results from the magnetopneumography indicated a mean clearance rate of dust in the lungs of 20% per year (range 10 to 30%). The results from the pulmonary function tests reveal that the retired welders were significantly below normal values, whereas the younger welders were within normal limits. Further evaluation of this study cannot be done in the absence of the complete presentation.

Unlike in the previous studies, Boylen et al. (1984) determined the acute effects of different fumes generated during welding on shipyard welders; 45 aluminum welders, 27 welders of stainless steel, and 74 mild steel welders were questioned and spirometry tests were performed on Monday before the usual workshift. The authors stated that 50% of nonsmoking aluminum welders complained of chest tightness and 25% of all other welders experienced chest tightness. Results from spirometry tests revealed that 36% of mild and stainless steel welders who smoked showed a decrease in flow rates, and 36% of stainless steel welders who smoked showed reduced vital capacity. Twenty-five percent of all other welders had a decrease in flow rates and sixteen percent had a decrease in FVC > 5%. Therefore, mild-steel welding reduces flow rates and stainless-steel welding reduces flow rates as well as vital capacity. From these preliminary results, the authors stated that it appears that symptoms of pulmonary irritation and metal fume fever were associated more with aluminum welding than with stainless steel and mild steel welding. Because the paper was available only as an abstract, complete evaluation of the work cannot be made.

**Estimation of Retained Particles in the Lung.** Magnetopneumography was developed over a decade ago for the measurement of ferromagnetic particles (primarily magnetite) in the lungs and has been used by several research groups to estimate retention of particles in the lungs of welders. This effort is relevant since ferromagnetic particles constitute as much as 30% of welding fumes and dust (Lippman, 1985). Basically, in this procedure, a strong magnetic field is applied to the chest for a few seconds, thereby magnetizing the lungs and any particles in them by creating dipoles within the particles to rotate the magnetized particles into common alignment. The magnetic field is then removed and the remaining magnetic field, or remanent field, produced by the magnetized particles within the lungs and the

relaxation times are measured with a magnetometer. The strength of the remanent field at the time the magnetizing field is removed is related to the amount of dust in the lungs. The relaxation time is thought to be due to a process of random reorientation of the particles in the lungs. Relaxation times have been hypothesized to be mediated by such factors as age, degree of retention, smoking habits, airway diseases, the length of time that the particles have been retained in the respiratory apparatus, particle size, and magnetopneumographic technique. To date, three different magnetopneumographic techniques have been used: the uniform field method, in which the entire thorax is magnetized for about 15 seconds; the localized field method; and the alternating current bridge.

Näslund and Högstedt (1982) measured ferromagnetic levels in 187 welders with at least five years experience and homogenous exposure using the uniform field method and related it to frequency of chronic bronchitis, as determined by the BMRC questionnaire for chronic bronchitis. Welders showed an increased magnetite deposition compared with two age-matched control groups. Interestingly, as previously reported (*Effects of Welding on Health IV*) smokers had lower levels of remaining ferromagnetic particles than did nonsmokers, an observation that the authors attributed to faster tracheobronchial clearance due to increased mucous production. The authors observed a dose-response relationship in the incidence of chronic bronchitis in smokers and nonsmokers by magnetopneumography, an effect confirmed in further studies by the same researchers, Högstedt et al. (1983) and by Freedman et al. (1982, 1984), who used a localized field technique. Freedman et al. also found that ferromagnetic content correlated well with the number of years of welding ( $p < 0.01$ , Spearman rank correlation). It is important to note that because ferromagnetic retention is not occupation-specific, an extensive job and hobby history should be obtained from all individuals studied.

Pilot studies have recently been conducted using a new magnetopneumography field technique based on an alternating current susceptibility bridge. The measurement derived is theoretically less sensitive to the relaxation mechanisms, which introduce a time-dependence to the remanent field after magnetization and therefore must be measured by uniform field and localized field techniques. Susceptibility bridge measurements are sensitive to all forms of magnetic material: diamagnetic, paramagnetic, and ferromagnetic substances of both endogenous and exogenous origin (Stern and Drenck, 1982). Using this method, Stern et al. (1985) have found a high degree of correlation ( $R^2 = 0.49$ ,  $p = 0.0001$ ) between median inferred lung burden of welding fumes and relative lifetime occupational exposure in 59 nonsmoking shipyard

welders with more than five years of work experience. Net thoracic magnetic moment was measured to determine retention of welding fumes. The change in thorax magnetic moment observed in a welding cohort, compared with controls who were electricians, is equivalent to a median of 110 mg magnetite. This corresponds to a median lung burden of 220 mg of magnetite. No difference was observed in chronic bronchitis incidence or average lung function parameters. The researchers concluded that this field method would not be useful for detecting clinical abnormalities until further baseline data were collected, especially from studies that follow individuals from entry into the welding profession across a significant fraction of their working lifetimes.

**2.2 Metal Fume Fever.** Ulvik (1983) reported a case of a healthy 34-year-old welder suffering from zinc fever. The welder was occupationally exposed for approximately five hours to welding fumes that penetrated his mask because of a defective filter. These fumes were analyzed and found to contain 3.5% zinc. Further analysis of the fumes did not reveal the presence of lead and cadmium, which often contaminate zinc-containing material and may also cause similar symptoms.

Symptoms of zinc fever began to appear 2 hours after exposure and reached a plateau after 5 to 6 hours before gradually subsiding within 24 hours after the disease started. Blood samples were taken at 6 hours, 23 hours, and 6 days (normal reference value) after onset of symptoms. The leucocyte count and lactate dehydrogenase concentration were expectedly high, but the erythrocyte sedimentation rate, hemoglobin concentration, serum protein electrophoreses, bilirubin, and electrolytes were normal. Relative to the patient's own reference value (day 6), serum zinc concentrations were decreased by approximately 15% and 29% at 6 hours and 23 hours, respectively, after the symptoms appeared.

Serum zinc levels have been reported only rarely in the zinc fever literature. One 1926 study reported elevated zinc levels, but Ulvik questioned the accuracy of methods in use then. Two studies have reported normal levels. In one, however, the serum zinc levels were not measured until two weeks after the initial exposure; in the other, neither the time after exposure at which the blood sample was analyzed nor the method and its limitations are described.

Ulvik's study does not support the notion that increased serum zinc concentration is a basic part of the pathogenic mechanism in zinc fever. The investigator is uncertain why the serum zinc concentration was lower in the acute phase of zinc fever but cites a previous hypothesis that it is a nonspecific response to local inflammation in the lung tissue. (Low serum zinc is a common characteristic of inflammatory conditions and tissue damage.) The

author suggests that more detailed studies are needed to clarify the pathogenic mechanism of zinc fever.

Acute exposure to aluminum can also cause metal fume fever. In a paper discussed in detail elsewhere, Boylen et al. (1984) reported that 65% of the nonsmoking aluminum welders and 33% of the stainless steel and mild steel welders experienced metal fume fever symptoms. It is apparent from the report that metal fume fever is more prevalent among aluminum welders than among stainless steel or mild steel welders.

**2.3 Effects on the Cardiovascular System.** Changes in the bronchopulmonary and cardiovascular systems of about 500 welders exposed to low- and high-alloyed steel welding relative to 200 control workers were described at a recent meeting by Krasnyuk et al. (1985), but only an abstract was available for review. Chronic bronchitis was detected in low-alloyed steel welders, and neuro-circulatory dystonia and metabolic changes in the cardiovascular system were found in the high-alloyed steel welders. Details on the nature of these metabolic changes were not provided in the abstract. The differences found in the pathology of respiratory and cardiovascular systems were attributed to the different chemical compositions of aerosols generated by high- and low-alloyed steels. This conclusion was based on the higher content of chromium in blood and manganese in hair of the high-alloyed steel welders in comparison with the low-alloyed steel welders. No other details of the experiment were provided.

**2.4 Effects on Kidney Function.** The etiology of kidney diseases induced by metal welding fumes is unclear. Epidemiological evidence of the occurrence of kidney disease among welders is generally lacking except for a few recent studies attempting to demonstrate a correlation between welding and renal disease.

Because of an apparent cluster of kidney disease in welders, Lindquist (1983) reported on a pilot study in Umea, Sweden. From 1978 through 1981, 18 welders were admitted to the Umea Medical Department with kidney disease (Lindquist, 1983). One woman and seventeen men with an average age of 34 years (range, 19 to 65 years) were diagnosed by kidney biopsy immunofluorescence. The kidney biopsy material was not analyzed for the presence of metals. Ten patients had welded for more than ten years, and eight for less. Actual exposure levels were not reported, but a subjective description of either "poor" or "good" ventilation was provided.

Six welders were diagnosed as having interstitial nephritis, three with IgA glomerular nephritis, two with membranous glomerular nephritis, one with glomerular nephritis type minimalis, and two with arteritis. Four patients had only proteinuria/hematuria. An obvious

correlation between the quality of ventilation and severity of these pathological changes could not be demonstrated by the investigators. Lindquist did not report on the number of welders in the area served by Umea Hospital. If this is an area of heavy welding, 18 welders hospitalized for kidney disease may not be in excess. The authors specify that it is unclear whether the risk is eliminated. The epidemiologic studies that are planned should answer that question.

Changes in low molecular weight (LMW) proteinuria, an indicator of defective reabsorption in the proximal tubuli, and  $\beta$ -hexosaminidase excretion in urine, which is a sign of damaged tubular cells, are sensitive indicators of renal disease. In a study by Littorin et al. (1984) using these methods, no signs of kidney damage were detected in 17 male, manual metal-arc stainless steel welders whose mean age was 45 years old (range, 34 to 64) and whose exposure to welding was considered "intense" for a mean period of 20 years (range, 17 to 41). For each welder, an individual matched on age (within 5 years), sex, smoking, approximate alcohol intake, social class, and drug consumption was selected. The authors did not provide information on the sampling frame for the controls, on the criteria for control, or on factors besides age or sex other than that the controls were individuals without occupational exposure to stainless steel or chromium. Interviews and clinical examinations revealed that only one welder was under treatment for hypertension; all other subjects showed no evidence of significant disease. Analysis of blood and urine samples revealed no significant differences between welders and controls for erythrocyte sedimentation rate, hemoglobin level, erythrocyte count, white cell count, and uric acid, albumin, creatinine, and glucose levels, although the authors did not present the data in detail. They noted that chromium has previously been associated with proximal tubular kidney damage in experimental animals and also in humans after heavy oral doses of chromium. Therefore, the chromium content in the urine of welders was assayed by Littorin et al. (1984) using the direct flameless atomic absorption spectroscopy method. Urinary chromium levels, both in the morning and afternoon, were found to be far higher in welders than in controls (median 23 vs 1.5  $\mu$ mole creatinine,  $p < 0.001$ ), indicating an accumulation of chromium in the kidney. Unfortunately, the authors ignored the matching in the analysis of chromium, and thus the true association is stronger by an unknown amount. However, the amount of chromium in the kidneys of these welders was considered by the authors to be probably much less than in animal experiments or in previous reports of accidentally poisoned humans. The authors concluded that there was not evidence of damage to either the glomeruli or renal tubules in these stainless steel welders.

Chronic renal tubular dysfunction was observed in a study of 22 welders, 22 to 55 years of age, who had been exposed to cadmium oxide fumes for a period of 7 months to 23 years (Toda et al., 1984). Welders were divided into three groups (high-, middle-, and low-excretion) based on determination of urinary cadmium levels, which varied from 5.7 to 184.9  $\mu$ g per day. Cadmium excretion had a correlation coefficient of 0.39 with number of years of cadmium exposure. Hematological, liver function, respiratory function, and radiological examination confirmed the exposure to cadmium. Thus, it would appear that cadmium excretion can be taken as a surrogate of total cadmium exposure in view of the probable variation in intensity of cadmium exposure over the years, which would cause some misclassification in using duration of exposure as an indicator of total dose. Workers in the high-excretion group complained of coughing, sputum, dryness of nose, and rhinitis and were characterized by increased urinary calcium and  $\beta_2$ -microglobulin; however, decreased levels of creatinine clearance and percent of tubular reabsorption of phosphate, calcium, and  $\beta_2$ -microglobulin were observed.

In all welders, the following relationships were significant: urinary cadmium and phosphate excretions [correlation coefficient ( $r$ )  $r = 0.4689$ ,  $p < 0.05$ ]; urinary cadmium and calcium excretions ( $r = 0.6844$ ,  $p < 0.01$ ); and urinary cadmium and  $\beta_2$ -microglobulin ( $r = 0.5083$ ,  $p < 0.05$ ).

Therefore, this study indicates that exposure of welders to cadmium oxide fumes can be associated with kidney damage because chronic renal tubular damage occurred in all five of the welders placed in the high-excretion group, with one showing considerable damage.

**2.5 Biological Monitoring.** There has been a continuing search for methods to establish more exact dose-response relationships between welding fume exposure and health effects. A number of professional years in welding has typically been used as a rough indicator of exposure in the absence of other data. This section reviews the recent efforts of various investigators to identify reliable biological parameters of exposure to chromium, nickel, cadmium, fluoride, aluminum, and manganese.

The measurement of chromium levels in the urine of welders has been extensively investigated as a possibility for monitoring occupational exposure to chromium (Sjögren et al., 1983a). However, lack of information on the kinetics of chromium excretion from the body has hampered efforts to make estimates of exposure. Welinder et al. (1983) measured chromium and personal air chromium levels in three groups of stainless steel arc welders. By measuring urinary levels in 9 welders who had been retired for an average of four years, 14 welders both before and after a 30-day vacation, and 20 active

welders, a two-compartment model for elimination of chromium was demonstrated. The fast-elimination compartment consisted of a chromium half-time of several hours (range 4 to 35 hours), significantly correlating chromium in total personal air to urinary chromium levels ( $p < 0.01$ ). The slow compartment half-time was more approximate, ranging from 14 days to infinity. Retired workers excreted significantly higher levels of chromium than nonexposed controls (7 and 1.5  $\mu\text{mol/mol}$  creatinine respectively,  $p < 0.001$ ) but did not differ from the welders who had been on vacation for 30 days (9  $\mu\text{mol/mol}$  creatinine). Active welders and welders before vacation had urine levels of 34 and 45  $\mu\text{mol/mol}$  creatinine, respectively. Chromium levels in active welders decreased from 34 to 19  $\mu\text{mol/mol}$  creatinine after a two-day weekend ( $p < 0.005$ , one-tailed), and from 45 to 33  $\mu\text{mol/mol}$  creatinine from postshift Monday to preshift Tuesday ( $p < 0.01$ , one-tailed). This pattern indicates a rapid initial decrease in the urinary chromium level after the end of exposure, then a slower change much later. There was good correlation between air and urine concentrations at the higher air concentrations, but the variation was too extreme at low air concentrations to make urinary chromium a good predictor of occupational exposure in these welders.

Sjögren et al. (1983a) measured personal air and postshift urine levels of chromium in 53 stainless steel arc welders on the same working day to determine to what extent postshift urine chromium measurements could be used to predict current chromium concentrations in the air. A linear relationship between concentration of total chromium (including hexavalent chromium) and mean postshift urinary level among welders was observed ( $r = 0.72$ ,  $p < 0.0001$ ). The time-weighted air chromium concentration was 124  $\mu\text{g}/\text{m}^3$ , and the mean postshift chromium concentration in urine was 718  $\eta\text{mol}/\text{l}$ . There was no relationship between exposure time, expressed as working years, and urine concentration, and there was no difference between smokers and nonsmokers. Since not only current exposure but also previous exposure contributes to urinary chromium concentrations, it is not sufficient to make a single urinary measurement to estimate chromium exposure.

Mutti et al. (1984) attempted to relate time-weighted workroom air exposure to various forms of chromium (such as hexavalent, trivalent, and zinc and lead chromium compounds) with urine levels in 36 MMA/SS welders and 12 MIG/SS welders. An increase in the chromium concentration in urine over the working day was related only to hexavalent, water-soluble chromium in air, consistent with the hypothesis that only water-soluble hexavalent chromium compounds are readily absorbed by inhalation. Neither trivalent chromium nor lead or zinc chromates were observed to increase during

the work day, as determined from urine analysis. Therefore, urine analysis was recommended only for the estimation of hexavalent chromium.

Rahkonen et al. (1983) examined chromium and nickel levels in 10 healthy MMA/SS welders with an average of 13 working years with stainless steel welding. During one workweek, personal air was measured throughout the workday; blood, plasma, and urine samples were taken pre- and post-shift; and spot urine samples were taken during a follow-up period. Magnetopneumography was conducted to measure retention rate of magnetic dust in the lungs. As in the study of Mutti et al. (1984), a linear relationship ( $p < 0.05$ ) between hexavalent chromium in the air and chromium in urine was observed. Correlations were not observed between chromium concentrations in whole blood and plasma and exposure to hexavalent chromium; the best correlations were found between the daily mean increase in the chromium in whole blood and the total chromium or hexavalent chromium in air ( $p < 0.001$ ). Using a single exponential functional fit, biological half-time of chromium was estimated at  $2.0 \pm 0.5$  days in plasma. Correlations were observed between chromium and hexavalent chromium in personal air samples and the mean daily increase of chromium in blood ( $p = 0.001$ ) and the retention rate of magnetic dust in lungs ( $p < 0.001$ ). Large variations were observed in the preshift urine and blood samples (0.1–2.7  $\mu\text{mol}/\text{l}$  and 0.05 to 1.43  $\mu\text{mol}/\text{l}$ , respectively), possibly indicating different body burdens of chromium in the welders.

In summary, further investigation is necessary to determine whether urinary chromium levels are a reliable index of exposure, because of the variability of individual factors, such as pulmonary ventilation and chromium body burden, environmental factors, and physical properties, including the portion of chromium soluble in water.

In the same study, the concentration of nickel in the urine increased 11% during the work day, which correlated with the concentrations of nickel in the air ( $p < 0.01$ ); the mean nickel concentrations, 11.5  $\mu\text{g}/\text{g}$  creatinine (range, 7.8 to 26.5  $\mu\text{g}/\text{g}$  creatinine), also correlated with the nickel concentrations in air ( $p < 0.01$ ). The nickel concentration in whole blood did not differ between welders and controls.

Sjögren et al. (1983b) measured aluminum in both the blood and the urine of various industrial workers, including aluminum welders, to determine whether aluminum was absorbed from the occupational environment. A linear relationship was observed between years of welding exposure and urinary aluminum concentration when adjusted for creatinine ( $r = 0.64$ ); this relationship was not explained by concentrations of aluminum in the drinking water or ingestion of drugs

containing aluminum. Blood aluminum levels showed no such relationship. There was a linear relationship between blood and urine aluminum concentrations, which was due largely to some individuals with extremely high values of both.

Jarvisalo et al. (1983) measured manganese levels in the urine and personal air of five nonsmoking, healthy shipyard MMA/MS welders who had five to nine years of work experience. The core rod they currently used for welding contained less than 1% manganese. Total dust concentrations were measured gravimetrically, and filters were placed within the face masks of welders to measure two 4-hour samples — one of dust and one of air. Spot urine samples and venous blood specimens were collected six times during the week. The study revealed wide variations in airborne concentrations of manganese in the personal air of the workers, perhaps reflecting different working habits. These values ranged from 8.9 to 56.3 mg/m<sup>3</sup> of dust for the worker with the greatest exposure; manganese varied from 0.30 to 2.30 mg/m<sup>3</sup>. The urinary concentration varied from 11.7 to 35.6  $\eta$ mol/l; the highest concentrations were observed in nighttime samples. Good correlations ( $r = 0.89$  and  $0.63$ ) between the time-weighted average of manganese levels in air and urinary levels were observed in only two workers; otherwise, there was no systematic correlation. Urinary concentrations of manganese in most of the welders were significantly elevated over levels in nonexposed controls ( $9.7 \pm 11.7 \eta$ mol/l,  $p < 0.005$ ). The range of concentrations of manganese in the blood did not vary significantly; however, blood concentrations in welders were elevated significantly over blood concentrations in the nonexposed control group ( $25$  to  $32 \eta$ mol/l compared with  $14 \pm 2 \eta$ mol/l,  $p < 0.05$ ). Because of the small numbers of samples taken during the study, it was not possible to determine the suitability of blood sampling for estimating manganese exposure.

Bergert et al. (1982) measured manganese concentrations in urine, feces, and hair of welders and the nonexposed controls. Manganese concentrations in urine were  $271.75 \pm 84.98 \eta$ mol/l in welders, compared with  $163.07 \pm 54.42 \eta$ mol/l in controls. In the feces, levels of  $594.23 \pm 239.15 \mu$ mol/g were found in welders, compared with  $506.23 \pm 177.63 \mu$ mol/g in controls. In hair samples,  $341.90 \pm 207.16 \mu$ mol/g in welders were found, compared with  $58.42 \pm 39.49 \mu$ mol/g in controls.

The possibility of monitoring individual manganese exposures from concentrations in biological fluids is complicated by the wide interpersonal variations in observed concentration due to differences in working habits, and the fact that sources of manganese other than occupational sources may be important.

Baddely et al. (1983) used a neutron activation technique to measure cadmium levels in 130 potentially

exposed workers, including smelters, electroplaters, and welders. Other industrial workers served as controls. This method was used because blood and urine concentrations generally have not reflected total body burden from chronic low-level exposure because of the kinetics of cadmium excretion; in this investigation, blood and urine concentrations also correlated poorly with neutron activation analysis. In the exposed worker population, 36 out of 130 had liver tissue levels above 20 ppm and 11 had liver tissue levels above 30 ppm. The investigators did not consider these levels to indicate a serious health hazard in those industries since only 2 workers out of 130 had levels greater than 50 ppm, the level associated with chronic cadmium nephropathy. This study demonstrated the utility and convenience of neutron activation analysis for industrial screening and confirmed the lack of utility of blood and urine sampling for monitoring cadmium exposure.

To monitor exposure of welding workers to fluorides, Sjögren et al. (1984) measured fluorides in the personal air, and the postshift urine of two groups of welders during four successive workdays. One group consisted of 11 stainless steel arc welders with 8 to 42 years work experience, and the other group consisted of 64 railway track welders who had worked with the OK 74.78 electrode, the fume of which consists of 18% to 20% fluorides, for 5 to 41 years. Welders had higher postshift urinary concentrations of fluoride than the controls ( $58 \mu$ mol/l, range 10 to 221  $\mu$ mol/l, compared with  $26 \mu$ mol/l, range  $< 10$  to 137  $\mu$ mol/l,  $p < 0.001$ , chi-square test).

In both groups of welders, a linear relationship was observed between postshift urinary fluoride concentration and total welding fume concentration (calculated as a time-weighted average) and airborne concentration of particulate fluoride ( $p < 0.001$ ). Postshift urinary fluoride concentrations remained similar during the course of the workweek, and there was no relationship between age and urinary fluoride excretion, suggesting that there was no tendency for bioaccumulation. From these data, it was considered possible to use urinary analysis to estimate exposure to particulate fluoride in welding fumes; a validity test for this prediction could not be performed because the number of test subjects was too small. However, the regression line indicated, with a 95% confidence limit, that a mean particle air concentration of  $5 \text{ mg/m}^3$ , the occupational exposure limit for nonspecific respirable particles in Sweden and the United States, corresponds to a urinary fluorides concentration of  $80 \mu$ mol/l. It is of interest to note that the levels of urinary fluoride observed in this study were lower than the levels reported to cause adverse health effects ( $370 \mu$ mol/l).

**2.6 General Morbidity.** Jinadu (1982) reported the results of a survey, in four towns in Nigeria, of three



occupational groups, one of which was welders, concerned with the repairs of motor vehicles. Because the conditions of this work in Nigeria appear to bear no resemblance — in terms of worker conditions and safeguards — to conditions in the developed world, this paper will not be reviewed in detail. In addition, the only comparison data reported by the author was for two other groups of workers in the industry — mechanics and painters — and it is not clear how comparable and appropriate these control groups are.

The results of a cohort morbidity study of 46 male welders by Kalic-Filipovic (1985) was presented to a symposium, but only the abstract of the presentation is available for review in this report. The sampling frame for the controls is chemical industry workers, but the method of selecting of the controls is not stated in the abstract. One potential cause of concern with selection of controls from one industry is that the results could reflect unusual risks in the control industry rather than in the industry of interest. For example, if welders were shown to have an increased risk of gastrointestinal diseases in comparison with the chemical industry workers, these results might reflect a very low risk of gastrointestinal disease among chemical industry workers and a risk similar to — or even lower than — that of the general population among the welders, or it could represent an increased risk of gastrointestinal disease among the welders. In the absence of any other data, there would be no way to distinguish between these possibilities.

The abstract reports brief results for broad categories of disease. A few results are presented in the analysis. The wording in the abstract is somewhat ambiguous, but, we assume that the percents given in the analysis are percents of welders affected rather than percents of total diseases. On that assumption, welders were over 15 times as likely as the controls to have skin diseases, nearly 3 times as likely to have diseases of the bones and joints, and about 2/3 more likely to have gastrointestinal diseases, particularly peptic ulcer. However, they were 30% less likely to develop chronic diseases of the respiratory system. Because of the need for brevity in the abstract, the author does not discuss the basis for the diagnoses. If the diagnoses were made, as seems likely, by different physicians in the two industries, these differences could easily reflect differences in diagnostic criteria rather than real differences in risk. However, if one or more physicians made the diagnoses, both for the welders and for the chemical workers, and used objective diagnostic criteria, these results would be much more valuable in determining whether welders are at increased risk.

Clearly, the value of this paper can be determined only upon publication of the full presentation. However, the information in the abstract suggests that this study is

unlikely to be helpful in determining whether there are health hazards from welding.

**2.7 Cancer of the Nasopharynx.** Lam and Tan (1984) studied this condition in Hong Kong, where it is relatively common. They carried out a proportional mortality analysis based on validated known deaths from 1976 to 1981 classified by occupation as given on the death certificate. The authors recognized the limits of this type of study, including limitations in proportional mortality analyses (discussed elsewhere in this report) and inaccuracies in occupation recorded on the death certificates. In the results that they reported, welders and plumbers were analyzed together. Since the exposures of plumbers are quite different from those of welders, and since it appears safe to assume that there are considerably more plumbers than welders in Hong Kong, the reported results have little application to the risk of welders. The authors rightly point out that the study can only be used to generate hypotheses. However, in view of the rarity of this cancer in Western countries, it appears unlikely that welding exposure is implicated in the etiology of cancer of the site.

**2.8 Nasal Cancer.** A case control study of nasal cancer and occupational exposure, including welding, was carried out in Finland, Sweden, and Denmark, where there are nationwide cancer registries (Hernberg et al., 1983a, 1983b). (However, in Denmark alone, the National Cancer Registry was not used as a source of cases and controls; instead, for practical reasons, cases and controls were ascertained from four of the five existing oncology centers in the country.) The cases studied were all new patients with primary malignant tumors of the nasal cavity and paranasal sinus diagnosed and reported to the sources in these three countries between July 1, 1977, and December 31, 1980. Each case was matched to an individual control for nationality, sex, and age at diagnosis (within 3 years) the controls being living patients with malignant tumors of the colon or rectum ascertained through the same National Cancer Registries during the same period of time. The first patient who met the matching criteria was always selected as the control, but at the same time a second control was selected according to the same criteria to be used in case the first control was dead or otherwise unavailable. The authors do not report the proportion of the time that a second control had to be used, but do mention that 6 cases had to be excluded from the analysis because controls could not be selected through this method.

Of the 287 cases, 167 were included in the analysis. In addition to the 6 who could not be matched with a control within the limits of the methodology, 45 were dead and an additional 69 were nonrespondents,

according to the authors in most cases either because of poor health or lack of a telephone. The authors provide information on cases included and excluded from the analysis, which is helpful in determining the generalizability of the results. The greatest difference in inclusion and exclusion was by country; the proportion of identified cases included in the analysis was approximately twice as high for Sweden as for Finland. This may reflect the proportion of households having telephones or the quality of medical care in the two countries. The other major difference is the primary site of the tumor; individuals having cancer of the maxillary sinus were the least likely to be interviewed, perhaps because this cancer has a poor prognosis. The proportions of cases included in the analysis according to cell type of cancer were quite similar in the three countries. The mean age of cases not included was higher than that age of those who were included, especially in Finland and least in Denmark, and more so for females than for males. This last finding may represent true differential noncooperation.

For each subject, a detailed occupational history was obtained for each separate occupation of more than 1 year's duration except for the 10 years preceding diagnosis in order to account for latency. An industrial hygienist blindly evaluated the exposure by category, one of which was "welding, flame cutting, and soldering."

This investigation has a number of strengths. At first glance, a case control study rather than a cohort study may be surprising. For most diseases, studying a cohort of welders is considerably more efficient in determining whether they are at increased risk of the disease rather than taking people with and without the disease, because such a small proportion of the population are welders. However, nasal cancer is so rare that it is considerably more efficient to study the proportion of welders in nasal cancer cases and controls than to determine the number of observed and expected nasal cancers in a cohort of welders. In SRI's two largest cohort studies (Client Private) combined, which represent a total study population of approximately 45,000 individuals and over 650,000 person-years of observation, there were no nasal cancer deaths. Consequently, it is not surprising that in much smaller cohort studies of welders (for example, that of Polednak reviewed in *Effects of Welding and Health IV*), no deaths from nasal cancer were noted.

In addition, a panel of pathologists reviewed all the cases to make certain that they were nasal cancers, a feature that is often absent from other such studies (frequently on the grounds of lack of funding or availability of interested pathologists). Because the cases were ascertained through population-based cancer registries, the use of such registries to act as a sampling frame for controls is most appropriate. Finally, the thorough review of occupational histories by an industrial hygien-

ist, including the allowance for the elapse of a latent period, is likely to minimize the potential misclassification by exposure.

Therefore, it is indeed unfortunate that the authors, having designed the study so commendably, introduced some features that made the results difficult to interpret. With a control group of all nonrespiratory cancers matched with these cancers from the same data source, there would be no question that the finding of an odds ratio of 2.8 for "welding, flame cutting, and soldering" would mean an increased risk of nasal cancer in welders. Unfortunately, the investigators chose as their control group cancers of the colon and rectum, so that this finding could reflect either a low risk of colorectal cancer among welders or a high risk of nasal cancer among welders, flame cutters, and solderers (or both). In fact, there may be some suggestion that welders are at low risk of cancer of the colon and rectum, as Polednak (1981), in a study reviewed in *Effects of Welding on Health IV*, found that the number of observed deaths from all digestive cancers (many of which are cancers of the colon and rectum) was less than half the number predicted from the experience of the comparable general population. In addition, Hernberg and coworkers reported data that took the matching into account only for welders, flame-cutters, and solderers combined, and in trying to interpret the risk for welders, solderers should be excluded. The authors do present a table giving some exposure information for subjects exposed to welding, flame cutting, soldering, chromium, or nickel. However, even this incomplete information does not indicate whether any of these cases are matched to any of these controls; in other words, the matching is broken and, as is well known, efficiency is lost. From the fragmentary information available, it is clear that there are 7 cases and 3 controls with welding exposure. If the matching is ignored (as it has to be in the absence of information on matching), an odds ratio of 2.4 is calculated. This, as already noted, could represent a lower risk than reality for colorectal cancer.

In summary, a well-conducted (in many respects) case control study shows that patients with nasal cancer are more than twice as likely to have an occupational history of at least 1 year of welding at least 10 years before the onset of the disease than are patients with cancer of the colon or rectum. However, it is not clear whether this represents a decreased risk among welders of cancer of the colon or the rectum or an increased risk of cancer of the nose and nasal sinuses among them.

**2.9 Cancer of the Larynx.** Sidenius et al. (1983) provided a case report of five cancers of the larynx within a five-year period among workers in a Copenhagen

machine factory with an average work force of 90 workers. Based on the incidence rate for cancer of the larynx in Copenhagen, the number of cancers of the larynx was 114 times the number expected. Although it is not clear whether the author used crude or adjusted rates to calculate the expected number of cancers of the larynx, age differences cannot explain such an extreme finding. As the authors note, chance is an extremely unlikely explanation. Two of the five laryngeal cancers were in welders. However, one had been employed for only four years in the factory and the other for only two years before the cancers were diagnosed. For these two individuals it would appear that the interval between onset of employment and occurrence of the cancer is too short for the cancers to be caused by these occupational exposures. In fact, of the five cases, only two had more than a five-year interval between onset of employment and diagnosis of cancer (one interval of 11 years and one of 20 years).

However, the working conditions, particularly with regard to industrial hygiene in this factory, are most unusual. The welding itself apparently has been stainless steel using argon gas shielding. Before this method, plated electrodes containing manganese, molybdenum, and titanium were used. There were continual improvements in the welding technology, but the methods used earlier than the last named are unknown. The factory did not install exhaust hoods in the welding area until 1974. At the time of the report, there was no fresh air intake in the factory except what came through cracks in the doors and windows. Heating in the factory was by the use of several heat turbines, which circulated the air in the room by sucking in the air, heating it to 70°C, and then expelling it. As the authors note through this process, the polluted air is mixed, heated, and spread over the one large room in the factory where the welding work and grinding (which is screened)-vice work, assembling, and drilling operations are located. In December 1977, personal and area sampling was carried out within this large room for chromium, copper, lead, manganese, zinc oxide, and iron oxide. Although all these substances were found in the air everywhere in this large room, in the welding and grinding areas the hygienic limits were exceeded. Depending on the sample, between 43 and 80% of the total dust was in substances other than what were measured. In contrast, oil mist measurements were only 30 to 40% of the allowed maximum values. In view of the work conditions, it would appear that not only the welders, but other workers as well, were exposed to chromium, nickel, and other substances from the welding processes.

In terms of other causes of cancer of the larynx, all five cases were cigarette smokers. Three smoked one pack a day and the other two smoked less but also smoked

cigars and took snuff. None of the five had a history of excessive alcohol ingestion.

The authors originally intended to carry out a case control study to determine the reasons for the excess of cancer of the larynx. They were unable to do so because of incompleteness of the records, both in terms of lack of availability of records on former employees and in terms of obtaining a complete work history on present employees. In the absence of this investigation, all that can be said is that there is a huge excess of cancer of the larynx in this factory, which may be related to occupational exposures originating in the welding area, but other occupational and nonoccupational causes cannot be ruled out. Three of the five cases have too short an interval between onset of an employment and diagnoses of the cancer for an occupational cause in the factory to be suspected, but, as the authors point out, something in the factory could be acting as a promoter.

Because of this report, a case control study of cancer of the larynx in welding in the entire country of Denmark was carried out (Olsen et al., 1984). The cases consisted of all newly diagnosed laryngeal cancer patients in Denmark between March 1980 and March 1982 who were under 75 years of age at the time of diagnosis. These cases were ascertained from hospital records of the five hospitals involved in treatment of laryngeal cancer in Denmark. For each case, four controls were identified using the municipal person registry in which the case was listed; these controls were matched to cases by residence, sex, and closest possible birthdate. Each subject received a postal questionnaire about their occupational exposure to a number of specific chemical and physical agents, including welding dust from stainless steel welding and welding fumes in general, as well as tobacco and alcohol use and other items.

Because very few females were exposed to welding fumes, the analysis reported by Olsen and colleagues was confined to males. Three mailings were sent out and missing information was handled either by returning the questionnaires to the subject or by interviewing the subject over the telephone. However, information on welding exposure was missing for 4% of the cases and 5% of the controls.

Of the 271 cases included in the analysis, 42 had welding fume exposure. Of the 971 controls included in the analysis, 115 had welding fume exposure. The risk varied considerably by anatomical location within the larynx. (Patients with cancer of the hypo- and oropharynx were excluded from the analysis.) There were 176 cases with glottic laryngeal cancer (i.e., cancer of the true vocal cord); of these, 23 were exposed to welding fumes. There were 79 supraglottic laryngeal cancers (i.e., cancers located above the vocal cords); of these patients, 13 were exposed. Five of the eleven subglottic laryngeal

cancers (i.e., cancers, located below the true vocal cord) were exposed. For all laryngeal cancers there was a weak association with welding fumes, which was of borderline statistical significance. (Although the authors reported several different statistical analyses, the results of each analysis were somewhat similar except that the analysis that retained the matching characteristics of the design showed stronger associations in each case.) When the cases were broken down by location within the larynx, there was essentially no association with glottic cancer, an association with supraglottic cancer (which in the matched analysis was of borderline statistical significance) that was a little stronger than for all cancers of the larynx, and a 6- to 8-fold increased risk for subglottic cancer, which was statistically significant in spite of the small numbers.

Among all laryngeal cancer patients, 50% of those exposed to welding fumes welded more than 15 hours a week, compared to only 21% of the exposed controls. Welders among the cases also had been welding longer on the average (22 years vs an average of 18 years for the welders in the control group). These data were not reported by anatomic location for laryngeal cancer but are compatible with a causal association.

The authors found similar findings for exposure to welding dust from stainless steel. However, the number exposed was much smaller (30 controls and 12 cases — 8 glottic, 2 supraglottic, and 2 subglottic). Therefore, statistical significance was not attained although the relative risk estimates were similar.

The authors were concerned about the so-called recall or memory bias (i.e., that the cases would be more likely to remember about exposures because they were stimulated to think about possible causes of their disease). In the introduction to the questionnaire, the participants were told that this was a study of the occupational causation of cancer of the larynx, but welding was not specifically mentioned. According to the authors, most other occupational exposures occurred with equal frequency among cases in controls (although they did not present the data) which would indicate that the positive findings for welding were not a result of this recall or memory bias.

The authors also examined the possibility of recall bias in another way. They believe that if that bias existed, cases would be especially likely to remember short-term welding exposures better than controls. Therefore, they reanalyzed the data by reclassifying all those exposed to welding for less than five years in the nonexposure category. This somewhat weakened the association with supraglottic laryngeal cancer and somewhat strengthened the one with glottic laryngeal cancer, and left the subglottic cancer association essentially unchanged.

For all cancer of the larynx patients, the increased risk with exposure to welding dust was seen only in smokers. However, among the cases, there were only 13 nonsmokers, so these data do not permit a determination of whether exposure to welding dust in nonsmokers increases the risk.

The authors were rightly concerned about the differential nonresponse between cases and controls. Ninety-six percent of the cases participated but only seventy-eight percent of the controls did so. The refusal rate among the controls was higher in the rural districts than in Copenhagen and was at its highest among the elderly. As the authors noted, a high proportion of welders among the nonrespondents in the control group could explain the present finding in the absence of an increased risk from welding. However, their impression was that people who had not been occupationally exposed to any of the potential hazards mentioned in the questionnaire were less likely to respond; if so, the association with welding exposures is underestimated. The authors noted that most of the nonrespondents came from the agricultural areas of the country which reinforced this impression.

The authors specifically noted that the cases reported in the factory by Sidenius and her colleagues were not included among the cases (because they had been diagnosed earlier).

This is, in general, a very well-conducted study. It shows a weak association between cancer of the larynx as a whole and either welding fume or stainless steel welding dust (which contains the carcinogens, hexavalent chromium and nickel), between welding fume and supraglottic cancer, and between stainless steel welding dust and glottic cancer. These relatively weak associations could be easily explained by a common underlying factor. For cancer of the larynx as a whole, the risk increases with the number of years as a welder and particularly with the number of hours per week spent welding, which weakens the possibility of a common underlying factor explaining the results. In addition, the study provides strong evidence that welding exposures cause the relatively rare (4% of this Danish series, 1% of all laryngeal cancers in the U.S.) subglottic laryngeal cancer. Because subglottic cancers make up such a small proportion of all laryngeal cancers, a causal association with subglottic cancers but no association with other laryngeal cancers would only result in a weak overall association for cancer of the larynx.

Just such a weak association was found by Sjögren and Carstensen (1985); they found 22 cancers of the larynx compared to 17.3 expected. Their abstract is discussed in more detail elsewhere in this report.

**2.10 Lung Cancer.** Blot et al. (1980) carried out a case control study of lung cancer in the Tidewater area of

Virginia. This part of the country was selected because the county mortality rates in the U.S. between 1950 and 1969 for lung cancer were elevated in this part of Virginia, an area where shipbuilding had been a major source of employment. The emphasis of the study was primarily on shipbuilding. Blind interviews were completed with 89% of the lung cancer patients and 82% of the controls. In each case, the interview was with the next of kin or other relatives and friends, and the proportion of interviews in cases and controls for each of these types of surrogate was comparable, after excluding 2% of the individuals when information was incomplete, 3% who had lived in Tidewater less than five years, and another 2% who "did not qualify as cases or controls." The final analysis was based on 336 patients who died from lung cancer during the year 1976 and 361 controls who were systematically selected from the mortality listings, after excluding all respiratory cancer and chronic lung disease, to resemble the cases with respect to race, age, year of death, and county or city of residence.

Most of the results reported and the discussion dealt with whether the subject had worked in a shipyard. However, the authors did report that 11 lung cancer cases and 9 controls had worked as a welder or burner in shipyard trades prior to 1950. These data give a crude odds ratio of 1.32 which is slightly lower than the odds ratio reported by the authors for shipbuilding in general. (The authors noted that comparisons may have been affected not only by the slightly lower response rate among the controls, but also by publicity surrounding the issue of asbestos and cancer and by limitation of occupational information obtained from next of kin, as opposed to the subjects who, had they been able to be interviewed — would presumably be able to provide a more complete occupational history.)

This is a reasonably well-conducted study, and the authors are well aware of the limitations of their data. However, a cohort study of the shipbuilding industry would have been a better way to test the hypothesis because lung cancer is a relatively common cause of death. The slightly increased risk among welders, as will be noted, is similar to risk estimates found in cohort studies of welders and probably does represent a mildly increased risk. Because the increased risk of lung cancer among all shipyard employees is secondary to this risk from asbestos exposure, which has been shown numerous times, in the absence of further information it seems reasonable to conclude that if there is an increased risk of death from lung cancer among these welders, it is probably a result of the asbestos exposure rather than welding fume exposure in the shipyard.

In a 1981 review, Stern stated that he combined the results of four cohort studies and one case control study of lung cancer in welders, but he did not identify the

studies that were combined. According to Stern, these five studies have an aggregate study population of 150,000 welders with approximately 420,000 person-years of observation. There were 415 observed deaths from lung cancer, and 308 expected to give an SMR of 135. Without knowing which studies Stern combined, the appropriateness of this calculation cannot be judged. As a minimum, it seems dubious to combine a case control study with cohort studies in this manner because of the way the data are ascertained.

Several studies that have been discussed extensively elsewhere in this report with regard to their strengths and weaknesses have reported results for lung cancer as well. Sjögren and Carstensen (1985) found 193 lung cancers reported to the Cancer Registry for a Standardized Incidence Ratio (SMR) of 1.42, and Sjögren et al. (1985) reported an SMR of 134 for pulmonary tumors when the same sample of welders was followed until death. Gallagher and Threlfall (1983) reported a Proportionalized Mortality Ratio (PMR) for lung cancer of 145 based on 74 deaths. Coggon et al. (1984) found a relative risk of lung cancer of 1.3 for individuals with an occupational history of solder exposure and 1.0 for individuals with "high exposure" to solder. (As noted elsewhere, it is not clear how much these last results relate to welding exposure.) In their abstract, Santi et al. (1985) state that they found a slight, nonsignificant increase in lung cancer risk among welders, but they gave no further data. McMillan and Pethybridge (1983) found that the number of observed deaths from lung cancer among welders was exactly equal to the expected number. In an abstract, McMillan (1985) mentioned that in the dockyard mortality study there were five deaths from bronchial carcinoma, but he did not give the expected number.

Newhouse et al. (1985) presented a paper on mild steel welders in a shipyard. Only the abstract of their presentation is available for this review. The records were of men employed between 1940 to 1968 and included 1027 welders, analyzed separately. Over 97% of the individuals were successfully traced for vital status, an excellent result. Newhouse and her colleagues reported an SMR for lung cancer of 114 among the welders. No further data are available, but the authors state that they intended this investigation as a "a useful pilot study" and are likely to carry out more comprehensive studies of stainless steel workers.

Beaumont and Weiss (1985) also presented at this symposium; only the abstract is available for review at present. Virtually all the results reported by the authors appear to be reported in their earlier papers reviewed in *Effects of Welding on Health IV*. However, they did report that if welding exposure can be considered causal for lung cancer, then among 100,000 welders there were 23.1 lung cancer deaths occurring as a result of welding

each year. In their abstract, they stated that the increased risk of death from lung cancer increases with increasing length of employment and interval since initial employment, which was the strongest predictor of excess risk. They also mentioned that the risk increased with increasing age, which is not surprising and not particularly helpful, because such a finding would be expected to occur whether or not there was an occupationally related risk of lung cancer. The increase with increasing duration of employment is compatible with an occupationally related cause. This paper cannot be completely evaluated until the proceedings of the entire symposium are available.

Sjögren et al. (1982) wrote a letter to the editor in response to the earlier paper of Beaumont and Weiss on lung cancer among welders that was reviewed in *Effects of Welding on Health IV*. In their letter, they presented some data from their survey of cancer among welders and gas cutters from the Swedish census data, with 96 lung cancers observed and 66.64 expected, a finding which is highly statistically significant. They suggested, therefore, that the findings of Beaumont and Weiss for lung cancer in welders could be related to asbestos exposure. In their letter, they reported data from a 1980 study by Sjögren also reviewed in *Effects of Welding on Health IV*. In that study, Sjögren found 3 deaths from lung cancer with 0.68 expected, which, in spite of the low number of deaths, was statistically significant. Sjögren et al., therefore suggested that hexavalent chromium from stainless steel welding might also play a role in the results reported by Beaumont and Weiss.

Beaumont and Weiss (1982) responded to the letter by saying that they did not think asbestos and chromium were major factors in their study. For example, they found no mesothelioma deaths. [As noted in our section on mesothelioma, Sjögren et al. (1982) reported four mesothelioma deaths, which was more than three times the expected number.] Beaumont and Weiss also pointed out that "stainless steel welding constituted only a small percentage of the total welding performed (mild steel welding was predominant)." They also pointed out that Stern had proposed (in yet another paper reviewed in *Effects of Welding on Health IV*) that a very high relative risk for stainless steel welding might explain the overall excess lung cancer risk of about 40% in the welding literature. (As can be seen from the data that we have reported above, risks this high or somewhat lower have been found recently.) Beaumont and Weiss give as their opinion, however, that further study of welders not exposed to chromium or asbestos is needed before it can be inferred that workers not exposed to chromium or asbestos are free of excess lung cancer risk. They recommended that populations of mild steel welders not exposed to asbestos be identified and studied.

Waddington et al. (1983) described a number of investigations launched by the WHO Regional Office in Europe. These included a study of health effects of occupational exposure of welders to chromium and nickel. One component of this study is a mortality study of welders exposed to chromium-containing fumes, welders not so exposed (who will be used apparently as an internal control) and external general population controls. If these plans achieve fruition, papers and other reports of these investigations will be very important portions of future editions of the *Effects of Welding on Health*.

In summary, a number of studies have reported either no increased risk of lung cancer or a slight to moderate increase of less than 50% above expectation in welders. The data are consistent with an increased risk secondary to asbestos exposure; however, until some of the more specific studies mentioned above are actually carried out and published, it will not be clear how serious the problem is and whether, to the extent it exists, the increased risk can be entirely explained by asbestos exposure.

As is well known, cigarette smoking is a cause of a number of diseases, especially respiratory tract diseases. In cohort studies, where welders are compared with the general population for risk of diseases, information on cigarette smoking is nearly always not available to the investigators. When an increased risk of these diseases is found in such studies, this increased risk sometimes has been facilely attributed to cigarette smoking in a superficial analogy to the attribution of excess risk of mesothelioma in shipyard welders who were exposed to asbestos.

This analogy is not appropriate, because shipyard welders are all exposed to asbestos as a consequence of working in a shipyard, whereas not all welders smoke. Because some welders are nonsmokers, indirect examination of whether cigarette smoking can explain an increased risk of these diseases is possible, even in the absence of smoking information on individual welders.

As the magnitude of the SMR observed increases, it is less likely that cigarette smoking will be the underlying explanation for the increase. In evaluating the effects of welding on health, an even more important consideration is whether the SMR increased with increasing intensity or duration of welding exposure. If such a dose-response relationship is seen, the possibility that cigarette smoking may explain the association becomes quite remote because in order to explain the finding, cigarette smoking would have to increase with increasing intensity or duration of welding exposure. Because of their implications we have emphasized the magnitude of the SMR and particularly its relationship to the intensity and

duration of welding exposure in our presentation of the results of cohort studies of welders.

**2.11 Mesothelioma.** Barnes (1983) discussed all compensable, asbestos-related diseases occurring in New South Wales, Australia, between February 1968, when asbestosis became recognized by the Board in New South Wales as compensable, and December 31, 1983. There had been 197 compensable deaths among workers during this period — five in welders, all from mesothelioma. It is difficult to tell the number of deaths expected from mesothelioma in the absence of excess risk because Barnes does not give the total number of welders in New South Wales during this period and because the scientific literature contains little information about mortality rates for mesothelioma. However, it would appear that five deaths in welders is in excess of expectation, and that these welders therefore were at increased risk.

It seems reasonable to implicate asbestos exposure as the most likely cause of this probable increased risk of mesothelioma among welders in New South Wales. According to Barnes, during World War II asbestos was wrapped around welding rods to make them burn more slowly. Barnes examined several such rods at dock yards and found they were wrapped in crocidolite threads. Experimental use of one of these rods found air levels “many times greater” than 2 milligrams per cubic meter of air for chrysotile asbestos and over 1 milligram per cubic meter of air for crocidolite asbestos. Asbestos is the only known cause of mesothelioma, and the only other hypothesized cause — a mineral named zeolite — has only been reported to be associated with mesothelioma in Turkey.

McMillan (1983) also has described case reports of mesothelioma among welders. According to McMillan, Dr. Geoffrey Sheers has maintained a registry of all cases of mesothelioma occurring in Plymouth, England, which is the location of a very large British dockyard in Devonport. Also according to McMillan, the completeness of cancer registration has been “better than average,” although it has been estimated that 1 death in 13 is not detected because of men moving from the area. Between 1964 and 1978, 108 diagnoses of mesothelioma were made and confirmed histologically. Not surprisingly, 96 were among men who worked in the dockyard, and 3 of these decedents were welders. According to McMillan, between 1978 and 1981, four other welders in Plymouth are known to have died of mesothelioma. Although for reasons given above, expected numbers are not given, these seven deaths from mesothelioma among welders during this time period appear to be considerably in excess. Because shipyards are known to be places where there are high levels of occupational exposure to asbestos, once again it appears reasonable to ascribe this

probable excess of mesothelioma among welders to asbestos exposures in the shipyard.

McMillan and Pethybridge (1983) reported a proportional mortality analysis among welders and other workers in the same dockyard. Included in the analysis were all individuals who had been employed for at least six months and had retired or died while still employed at the dockyard in Devonport between January 1, 1955 and December 31, 1974. All these men were traced to determine which had died by December 31, 1975. Of the 2,568 men, 656 were deceased.

The authors stated that it was not possible to calculate standardized mortality ratios because the total population at risk was not assessed, presumably because the funding did not permit this to be done. Therefore, they had to settle for calculating proportional mortality ratios (i.e., the observed number of deaths divided by an expected number derived from the proportion of deaths from that cause in the comparison population). There are limitations in interpreting proportional mortality ratios when the expected numbers are derived from the general population proportional mortality, so perhaps for this reason, the authors used two other groups of deceased workers as control groups. These were boiler-makers and shipwrights who had moderate, intermittent exposure to welding fumes and gases, and electrical fitters, painters, and joiners who had little or no exposure to welding fumes and gases. This, unfortunately, only makes it even more difficult to interpret the results. Even the finding of a gradient of an increasing proportional mortality ratio for a cause by degree of welding exposure does not necessarily mean that welders are at increased risk of death from this cause. Such a finding could be explained through several other mechanisms in the absence of an increased risk of death from this cause in welders. Among such mechanisms are a decreased risk of death from this cause among boiler-makers and shipwrights and an even lower risk among the electrical fitters, painters, and joiners and, as a second possibility, an increased risk from all other causes among boiler-makers and shipwrights, and an even more increased risk from all other causes among electrical fitters, painters, and joiners.

For mesothelioma, the PMR was 259 for welders, 116 for the boiler-makers, and 24 for the electrical fitters and painters. This certainly describes a gradient of increasing PMR with increasing exposure to welding fume. In fact, as noted above, these data in themselves do not necessarily indicate that welders are at increased risk of mesothelioma; however, because it is well known that shipyard workers are at increased risk of mesothelioma, it is clear that even in comparison with other shipyard workers, welders are at an increased risk of mesothelioma. It appears unlikely that this gradient is caused by welding

fume exposure. In fact, the authors correctly ascribe this increased risk of pleural mesothelioma to asbestos exposure. McMillan and Pethybridge (1983) do note that there were no deaths from sinonasal tumors, whose risk is increased from certain exposures to nickel.

In summary, all of these papers show an increased risk of mesothelioma among welders in shipyards, and — just as clearly — in each case, asbestos exposure is responsible for this increased risk.

In the linkage of the 1960 Swedish Census with the Swedish Cancer Registry, Sjögren et al. (1982), in a letter to the editor, noted that there were 4 cases of mesothelioma in the welders and gas cutters identified in the 1960 National Census. According to these authors, the expected values, which are sex-, age-, and region of Sweden-specific, are 1.17 for mesothelioma, giving a standardized incidence ratio of 3.43, which was statistically significant. Sjögren and Carstensen (1985) presented linked data from the same sources at a 1985 meeting. According to the abstract of that presentation (all that is available for this update), there were still 4 plural mesothelioma cases, but the expected number had risen to 2.7, lowering the “risk ratio” (actually, as noted above, the standardized incidence ratio) to 1.49, a value that was no longer statistically significant. Presumably, the higher expected number represents later data, although until the presentation is actually published we will not be able to determine this. Evaluation of these data will depend on publication of the full presentation in order to determine the basis for the expected number of mesotheliomas. Until then, it is not clear what the risk of mesothelioma is among Swedes who identified themselves as welders during the 1960 census.

Baba (1983) reported the first case of mesothelioma in a welder in Japan. Because this man also had a diagnosis of asbestosis, his death in 1979 was presumably the result of asbestos exposure.

**2.12 Bladder Cancer.** There have been two recent reports of increased risk of bladder cancer among individuals occupationally exposed to solder in England and Wales (Coggon et al., 1984) and among solderers and welders combined in the United States (Miller et al., 1984). Neither of these papers will be discussed in detail because the exposed groups included both welders and nonwelders and no separate analysis was done on welders alone.

Preliminary results of a retrospective cohort mortality study of 2,190 longshoremen, including 214 welders in the Genoa dockyards between January 1, 1960 and December 31, 1979, have been reported (Santi et al., 1985). According to the abstract of the presentation, which is all that is available in time for this review, these preliminary results indicated an increased, statistically

significant risk of bladder cancer. In the published abstract, the authors did not report results separately for the welders but stated that in their presentation, they provided an analysis of risk of lung cancer among welders by length of exposure. Evaluation of this study and the results must await publication of the full presentation, probably a few months after the completion of this update.

**2.13 Kidney Cancer.** Sjögren and Carstensen (1985) have recently presented results of a cohort study at a meeting. For this review, only the abstract of their presentation is available. These authors took advantage of the fact that during the 1960 Swedish census, individuals were asked their occupation. This occupational information was linked with newly diagnosed cancers in the nationwide Cancer Registry. In addition, the authors state that they took deaths into account, although the abstract does not state how this was done. One correct way to do this would be to accumulate person-years for calculating expected numbers of cancers for individuals who died from non-neoplastic causes up until the date of death and then to cease accumulating these person-years for these individuals. The expected number of cancers are adjusted for sex, age, and region of the country.

The authors' presentation is confined to the 23,464 males 20 to 69 years old at the time of the 1960 census (October 2–8) and gave their occupation during that week as welders or gas cutters. Females were excluded because of small numbers. There were 70 newly diagnosed kidney cancers and 54.0 expected among these men. This 30% excess is statistically significant ( $p = 0.04$ ) because of the large numbers. In the abstracts, the authors briefly discuss the problems with misclassification, which are discussed in the review of this paper under Brain Cancer. They also pointed out that there may be subsets of the welders with much higher risk, but types of exposure within welding were not characterized in the census data.

Because the association is weak, it could easily be explained by a common underlying factor such as cigarette smoking or by biased misclassification if it were of sufficient magnitude. Consequently, all we can say is that the Swedish data, at least as reported in the abstract, suggest that welders are at an increased risk of kidney cancer. This finding needs to be confirmed or refuted by other independent studies.

**2.14 Brain Cancer.** Englund et al. (1982) have reported on brain cancer by occupation in Sweden. During the Swedish national census, which took place October 2–8, 1960, individuals stated their occupation. One of the categories was welders and gas cutters combined. Because each Swede has a unique nine-digit personal



identification number used on all records, investigators have been able to link occupational information recorded in the 1960 census with the occurrence of cancer in the National Cancer Registry between 1961 and 1973. After elimination from the data of children born after 1960 and immigrants to Sweden after 1960, 98.8% of the cancers reported from 1961 to 1973 have been linked to the 1960 census reports. According to the authors, unmatched records resulted almost entirely because of incomplete identification numbers.

The authors calculated age- and sex-adjusted expected numbers of brain cancers for different occupational groups, including welders. This enabled them to calculate "risk ratios" (in actuality, standardized incidence ratios) by dividing the observed numbers of brain cancers by expected numbers thus calculated. There were 50 brain cancers reported in the 25,935 welders, which gave an excess of observed-to-expected of approximately 35%. The authors reported 99% confidence intervals, which shows that the difference between observed and expected was not significant at the 1% level. Our calculations at the more conventional 5% level of significance show borderline statistical evidence.

In a recent abstract of a presentation at a meeting, Sjögren and Carstensen (1985) reported observed and expected brain cancers among the 23,464 males aged 20 to 69 during the 1960 Swedish census. The abstract did not give specific follow-up dates, but it appears that this follow-up is more recent because there were 68 observed brain cancers among this subset of all welders with 56.9 expected for a "risk ratio" of 1.20 which is no longer statistically significant at the 5% level. (Although we have conventionally referred to these cancers as brain cancers, they actually are malignant neoplasms of all parts of the central nervous system, virtually all of which are malignant neoplasms of the brain.)

As the authors point out, "certain misclassifications of both diagnoses and occupation are inevitable and have to be borne in mind when one interprets the results." Some of the welders on that date may have spent most of their working lives at different occupations, and some of the other individuals may have worked as welders but were not doing so during that census week. If this misclassification was completely random, it would not create a spuriously positive result but would tend to weaken any association found. If the misclassification were nonrandom, anything could happen, even false positive results. However, if the misclassification was minimal, even such biased nonrandom misclassification would not affect the results to a large extent. It seems likely that most welders were classed appropriately, and that the number of former welders among the rest of the Swedish population included in the analysis was too small a fraction to affect the results.

More serious is the problem regarding the accuracy of the diagnosis. The authors did not attempt to confirm any of the diagnoses. Brain cancers are sometimes undiagnosed or misdiagnosed. In the United States, there is some evidence (Greenwald et al., 1981) that employed populations in certain industries with excellent benefits in health insurance and fine employee medical services may be more likely to have their brain cancers detected. Greenwald and his colleagues call this effect "diagnostic sensitivity bias." Because of the universal availability of social insurance in Sweden, the Swedish authors point out there is no reason to believe that diagnostic sensitivity bias would be stronger *per se* in some industries than in others. However, they do show that in certain areas of Sweden where major cities are located, and particularly in Malmö and vicinity the "risk ratio" for brain cancer is extremely high — perhaps because of diagnostic sensitivity bias. If welders are more likely to be found in the Malmö area than in the rest of Sweden, the geographic differences could explain the findings.

Englund et al. (1982) performed an additional analysis on those individuals born between 1896 and 1940 and hence, would have been between 20 and 65 at the time of the 1960 census. They calculated incidence rates (the type was not specified, but it appears that these are annual incidence rates per 100,000, which are age- and sex-adjusted) for the entire Swedish population and for specific occupational groups. For the entire Swedish population, the incidence rate for all brain tumors was 12, and for glioblastomas, which are relatively common and the most serious prognostically, the rate was 5. For welders, the corresponding rates were 15 and 9. These figures indicate that if there is an increased risk of brain cancer in welders, the risk of glioblastomas is even higher.

Because of the uncertainties in the study described above and because such a relatively weak association can easily be explained by common underlying factors, at present, one can only say that there is a suggestion from some Swedish data that welders may be at increased risk of brain cancer, particularly glioblastoma. However, this finding needs to be confirmed before the association can be accepted as causal.

A case control study for brain cancer in Maryland (Lin et al., 1985) reported an odds ratio of 1.95 (in other words, nearly a twofold risk) of the specific brain cancers glioblastomas, other gliomas, and astrocytomas combined for a category that included welders. This category, which included electricians, dispatchers, highway patrolmen, electric, electronic, aerospace, and telecommunication engineers, television and radio repairmen, electronic service repairmen, and telecommunication industries repairmen was set up by the authors because

they felt that individuals in these occupations were probably exposed to electromagnetic fields. Results for welders were not provided separately, so it is not clear how much the results reported by Lin et al. (1985) apply to welders.

**2.15 Neuroblastoma.** This is a childhood tumor found primarily in the adrenal gland, although it can occur elsewhere. Recently, there has been interest in possible parental occupational causes of this cancer in the offspring. A case control study for this disease has recently been reported in an abstract by Kramer et al. (1984). They compared 104 cases diagnosed between 1970 and 1979 in a well-defined region known as the Greater Delaware Valley with 104 controls individually matched on year of birth (plus or minus three years), race, and first eight digits of the telephone exchange of the case of diagnosis. They reported statistically significant results, which indicate how likely the findings are to be caused by chance but do not present the strength of the association, which is more valuable as an indicator of how likely a confounding variable can explain the findings. Maternal occupational exposure to metal fumes and dust any time during the five years prior to the birth of the child was significantly ( $p = 0.01$ ) associated with risk of neuroblastoma. Paternal exposure to metal fumes and dust during the five years prior to birth was also significantly associated with the risk of neuroblastoma ( $p = 0.05$ ) but less so than the previously reported maternal exposure finding. Spitz and Johnson (1985) have noted that the exposure to metal fumes suggests the occupation of welders. However, they feel that the welders are exposed to electromagnetic radiation, which they feel is the important risk factor for neuroblastoma. In any event, the findings of Kramer and her colleagues imply that a large number of tests of significance were made, which means that even if there were no relationship, 1 in 20 would be conventionally statistically significant by chance alone. Therefore, the statistical significance of the exposure is less impressive than it might otherwise seem. Because not enough details of the study by Kramer et al. (1984) are given in the abstract, a complete evaluation of the relevance of that study to the effects of welding on health must necessarily await publication or provision of the full paper.

**2.16 Hodgkin's Disease.** Gallagher and Threlfall (1983) reported on a proportional mortality analysis on deaths in the province of British Columbia between 1950 and 1978. During that period there were 457,083 deaths in the province. Approximately 8% were eliminated from the data either because the individuals were under the age of 20 or because the records were part of "a small number" having invalid information on sex, occupation, or cause

of death. The authors examined the proportional mortality of 10,036 male metal workers. Because only seven deceased women were recorded as metal workers, they were excluded from the analysis. The authors apparently compared the proportion of deaths by cause in male metal workers and subsets, including 1002 deceased welders, with the proportion of deaths by cause among the 254,901 men over 20 who died in the province during those years and had valid information on their death certificates. (The word "apparently" is used because the wording in the paper regarding the source of the expected numbers is somewhat ambiguous.) Because these authors examined 216 occupations and 158 causes of death, the statistical significance of any of their findings has to be interpreted with caution; by chance alone, 5% of their findings would be statistically significant, and over 34,000 such comparisons were made.

The authors presented only limited results. They specifically stated that for other types of cancer within each occupational group for which the data were not presented, the proportional mortality ratios were "as expected." For welders, three causes were presented. The proportional mortality ratio for the 207 deaths from all cancers combined was 114, a finding which was of borderline significance. This is not an unusual value for such a PMR, and the statistical significance of the finding is not impressive in view of the number of comparisons that were made. This ratio is likely to be explained by chance and, regardless of the reason, is unlikely to be of clinical significance. More important, the nine deaths from Hodgkin's disease were nearly 2.5 times the expected number. Although this finding was statistically significant ( $p = 0.03$ ), approximately 1000 findings with that degree of statistical significance would be expected by chance alone. The other reported result for lung cancer is discussed under that disease.

The authors discussed a number of limitations in their data. First, they raised the possibility of inaccurate cause of death coding. As they note, this is reasonably reliable for most causes and even more reliable for specific cancers. This problem is not extensive enough to affect the results markedly. A potentially more extensive problem is inaccuracy of occupational information on the death certificates. However, Petersen and Milham (1974) found approximately 80% agreement of occupation given on the death certificate with that provided on interview with next of kin or other relatives. The biggest limitation of the data is the forced use of the proportional mortality ratio, the limitations of which are discussed extensively elsewhere in this report. However, according to Gallagher and Threlfall, the PMR for arteriosclerotic heart disease was near 100 (the null value), which makes less likely, a compensating excess in the proportional mortality ratio for specific cancers to coun-

terbalance a deficit in the most common cause of death nevertheless. However, an excess in a particular cause in the proportional mortality ratio could still occur in the absence of an increased risk, simply because the authors are forced to measure the proportion of deaths rather than the force of mortality.

The authors conclude that "the higher risk of Hodgkin's disease and multiple myeloma in welders in British Columbia is a new finding and will require confirmation in more detailed studies." Their conclusion is justified even more about Hodgkin's disease by the limitations of their methodology, particularly the forced use of proportional mortality ratio. Therefore, the findings on Hodgkin's disease require confirmation through better designed studies, although by themselves they do give some ground for concern.

The reference in passing to an increased risk of multiple myeloma in welders in this study is puzzling, because the authors do not present any data for multiple myeloma in welders. As noted earlier, they specifically stated that any data not presented was omitted because the observed and expected deaths were in very good agreement. They did find a proportional mortality ratio of over 200 for multiple myeloma in machinists and discussed this finding elsewhere in the paper. Presumably, the sentence was in error and the authors were referring to the elevated Proportional Mortality Ratios for Hodgkin's disease among welders and for multiple myeloma in *machinists* (not welders).

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### 3. Experimental Investigations

#### 3.1 Animal Studies

**3.1.1 Carcinogenesis.** The possible bronchocarcinogenic effects of fumes generated by two stainless steel processes, manual metal arc (MMA) welding and metal inert gas (MIG) welding, were examined in 70 hamsters by intratracheal instillation of either 0.5 or 2 mg of MIG and MMA fumes (Reuzel et al., 1985). Following once-weekly administrations for 340 days, the hamsters treated with high doses of MMA and MIG fumes showed increased lung weight, interstitial pneumonia, alveolar broncholization, and emphysema. Hamsters treated with 0.5 mg of MMA fumes or calcium chromate (VI) ( $\text{CaCrO}_4$ ) had similar changes that were much less severe. Histological examination revealed 2 malignant lung tumors in the MMA-exposed group; none were detected in any other group, including 791 historical controls.

In an attempt to study the possible bronchocarcinogenic effects of welding fumes containing chromium, Berg et al. (1985) collected and implanted fume particles as pellets in the bronchi of groups of 100 rats. The particles were shown to contain both tri- and hexavalent chromium in soluble and low-soluble forms. After 34 months, no significant differences were noted in growth rates, survival times, terminal organ weights, macroscopic and microscopic findings, and precancerous changes or tumors at the implantation site between the test and negative control groups. By contrast, a positive control group receiving pellets containing benzo(a)pyrene developed epithelial cell tumors in all rats. The significance of apparent negative findings, however, may be questionable because the implantation technique may not adequately mimic true human exposure by inhala-

tion in terms of absorption and bioavailability of the welding fume particles.

**3.1.2 Pneumoconiosis** The biological effects of various welding processes and their respective generated fumes were studied in rats by three investigators. Hicks et al. (1984) focused on the effects of MMA welding using flux-coated mild steel electrodes and MIG welding using stainless steel. Al-Shamma et al. (1983) examined an array of flux-coated electrode welding fume particulates, in more detailed analysis of fume effects. Finally, a study by Kennebeck (1985) was available for review only as an abstract, which did not provide details on the specific type of welding materials.

Hicks et al. (1984) compared the biological effects in rats of fume materials from MMA welding with flux-coated mild steel electrodes to MIG stainless steel welding by either inhalational exposure or intratracheal injection. The MMA fumes were obtained by the repeated consumption of flux-coated (FC) rutile-iron mild steel (MS) rod electrodes generating iron (metal and oxide forms) and silica (25% W/W as  $\text{SiO}_2$ ) particles, oxides of nitrogen ( $\text{NO}_2$ ) plus a mixture of other particles. A group of 40 rats were exposed to an average MMA/MS fume-particle concentration of  $1178 \text{ mg/m}^3$  for 46 minutes. Metal inert gas fumes were produced from stainless steel wire, Bostrand 61, consisting mainly of iron, chromium, and nickel. Twenty-four rats were exposed for one hundred eighty-four minutes to MIG/SS welding fumes having an average concentration of  $400 \text{ mg/m}^3$ . In a second experiment, 30 rats were exposed to an average concentration of  $580 \text{ mg/m}^3$  for 173 minutes. Animals were exposed to fumes drawn from the region of the arc and passed into a "head only" chamber. The animals were exposed for different lengths of time in these experiments because the concentrations of particulate material differed.

Samples of particulate material were collected from the welding processes and were suspended in saline for intratracheal administration of 50 mg of MMA/MS fume particles to each of 30 rats. In serial experiments, groups of 20 rats were given intratracheal doses of either 10 or 50 mg of MIG/MS or MMA/SS fume particles. The groups of animals were sacrificed at various times for histopathological examination.

Histopathologic changes in the rat lung tissue were compared at various times after inhalational exposures to MMA/MS and MIG/SS welding fumes. After two to five hours, widespread pneumonitis was observed in the lungs of rats exposed to either the MMA/MS or MIG/SS welding fumes. Two days after exposure to MMA/MS welding fumes, the pneumonitic exudate was reduced with some aveolar septal thickening. In comparison, pneumonitis persisted with more extensive

alveolar septal thickening two days after MIG/SS exposure. Peripheral alveoli became clear and free of visible particles between 7 and 21 days after MMA/MS exposure, whereas the alveolar epithelial thickening became more extensive, with particle-laden macrophages widely distributed in MIG/SS-exposed. Even 30 days after exposure, alveolar septal thickening was much more extensive in the MIG/SS-exposed rats. By 300 days, few particle-containing macrophages remained in the alveoli, thickening had mostly abated, peribronchial aggregates were well demarcated, and numerous well-formed, particle-engorged giant cells had appeared in the MMA/MS-exposed rats. At this time in the MIG/SS-exposed rats, the peribronchial clusters were also well developed, but more irregular, particle-laden cells and epithelial thickening were still extensive, and numerous giant-cells appeared that were misshapen and devoid of particles.

The histopathological changes in rat lungs were also compared after a single intratracheal injection of 50 mg of either MMA/MS or MIG/SS welding fumes. At 90 to 100 days after exposure, extensive and massive deposits of particles, some collagen formation, and aggregation of some multinucleated giant cells were observed in MMA/MS-exposed rats. At that time in the MIG/SS-exposed rats, deposits of particles were irregular and massive; evidence of macrophage activity was extensive, fibrous formation was slight; thickening of alveolar epithelium was extensive; and giant cells were present. By 450 days, distinct collagen development and occurrence of numerous, regularly shaped giant cells were observed in MMA/MS-exposed rats. The MIG/SS-exposed rats were characterized at this time by massive consolidation and epithelial-cell proliferation of particle-laden cells, little or no collagen, and numerous, irregularly shaped giant cells.

In summary, the study reported by Hicks et al. (1984) revealed some differences between the effects of the two forms of welding. The lung damage observed in rats included an initial effect consisting of acute inflammatory responses and a later effect associated with cellular changes and the persistence of dispersed or aggregated deposits of particles. The proliferative changes associated with pneumonitis included a thickening of alveolar epithelial septa, which occurred in response to either type of welding fume. Using alveolar thickening as an indicator, MIG/SS fumes appear to have caused greater and more prolonged pneumocyte damage than MMA/MS fumes.

Al-Shamma et al. (1983) conducted a similar rat study testing the separate components of flux-coated electrode (OK 46.00) welding fumes. Analysis showed the fumes to be composed of silicon dioxide particles, metals, metal oxides, nitrogen oxides, and hydrogen fluoride.

A group of 36 rats were exposed by inhalation to particulate matter for four hours then sacrificed, in groups of six, immediately and at 1, 7, 14, 28, and 60 days after exposure. In a long-term experiment, groups of 24 rats were injected intratracheally with 50 mg of a mixture of nitrous fumes, hydrogen fluoride, carbon monoxide, manganese, silicon dioxide, and iron and sacrificed at 3, 6, 8, and 10 months.

In both experiments, one day after exposure, rats had edema, acute pneumonitis, and hyperplasia or alveolar wall thickening, which were not apparent in rats sacrificed at later times. The authors suggest that the pneumonitis and edematous reaction were probably attributable to the high concentration of nitrous fumes and hydrogen fluoride, which are both known lung irritants. A statistically significant increase in the ratio of lung weight to body weight ratio of exposed rats was observed. The animals sacrificed at the later stages had fibrosis and nodules surrounded by bundles of collagen. The high levels of collagen were indicated by a significant increase in hydroxyproline levels. Most of the welding particles and macrophages were localized at the perivascular and peribronchial areas. The fibrotic changes observed suggest that silica was probably responsible.

In conclusion, each of the fume constituents had distinct harmful effects when administered either by intratracheal or inhalational exposure in rats.

The toxicity in rats of six welding materials that are used in shielded metal, gas metal, and flux core arc welding is described in a meeting abstract by Kennebeck (1985). After six hours of exposure, urine samples were taken and rat lungs were necropsied for microscopic examination. The lung tissues of rats that had been subjected to lung lavage were bloody or had reduced cell populations at 20 hours postexposure. Signs of pigmented macrophages and occasional focal acute pneumonitis, multifocal perivascular edema, and changes in lung weight were observed 14 days after exposure to each group of fumes tested. Out of the six fumes tested, the stainless steel electrode was determined to be the most toxic to rats.

Uemitsu et al. (1984) conducted an inhalational toxicity study on fumes generated from MMA/MS with a lime electrode (L fumes) and from MMA/SS with a lime-titania electrode (S fumes), a process that produces particles comparatively rich in nickel and water-soluble hexavalent chromium. Rats were exposed to 1000 mg/m<sup>3</sup> of either MMA/MS L fumes or MMA/SS S fumes for 1 hour, or to 400 mg/m<sup>3</sup> for 30 min/day, 6 days/week, for 2 weeks.

In the single-exposure study, microscopic abnormalities were found only in the lungs of rats exposed to fumes. The damaged lungs gradually returned to normal in rats exposed to L fumes, but the rats exposed to S

fumes after 14 days continued to show slight lung damage.

From repeated exposure to fumes, the rat lungs had histopathological signs of discoloration, weight change, and morphological changes only in rats treated to S-fumes. Significant ( $p < 0.01$ ) increases in the wet weight and relative lung weights approximately 1.2 or 1.7 times over controls were observed in L fumes—or S fumes—exposed groups, respectively. Respiratory irritation, such as mucous granules in the alveoli and hyperplasia of mucous cells in the bronchial epithelium, and bronchiectasia were also observed in the group exposed to S fumes. The authors suggest that the morphological abnormalities and respiratory irritation are attributable to allergic and irritant reaction to chromium, since this response cannot be explained by acidity or alkalinity of the weakly acidic fumes ( $\text{pH} = 6.6$ ).

In conclusion, the stainless steel welding particulates induced greater and longer-lasting effects in the lung of rats than did mild steel welding particulates.

**3.1.3 Whole-Body Effects.** The acute and subchronic toxicity of the following trivalent and hexavalent chromium compounds were studied in mice by Bryson and Goodall (1983) to determine the active forms of these compounds: chromium nitrate [ $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ], chromium trichloride ( $\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$ ), chromic sulfate [ $\text{Cr}(\text{SO}_4)_3 \cdot 15\text{H}_2\text{O}$ ], and chromium trioxide ( $\text{CrO}_3$ ). The acute toxicity of chromium nitrite, chloride, and sulfate salts; chromium trioxide; and potassium dichromate was tested by intraperitoneal administration in NZC male mice and in CXO male and female mice. The  $\text{LD}_{50}$  estimates on day 3 and day 10 were determined using 2 or 4 animals per group, at 5 to 10 different dose levels. Hexavalent chromium compounds were more acutely toxic than the trivalent chromium salts; the mean  $\text{LD}_{50}$ s (day 3) were  $17.8 \mu\text{g}/\text{g}$  and  $39.1 \mu\text{g}/\text{g}$ , respectively. However, the mean distal  $\text{LD}_{50}$ s were similar, regardless of the oxidation states of these compounds. Slightly more toxicity was seen in female than in male mice.

Subchronic toxicity and whole body retention were studied in mice by intraperitoneal injection of either trivalent chromium (III) ( $3.25 \mu\text{g}/\text{g}$ ) or chromium (3.23  $\mu\text{g}/\text{g}$ ), administered one time or weekly for 8 weeks (Bryson and Goodall, 1983). Because mice receiving multiple treatments of chromium (VI) showed signs of body weight loss (range 15% to 20% at the end of the eighth week, the intervals of injections were changed to every two weeks. (Dosages were one-sixth of the distal  $\text{LD}_{50}$  per injection.) The whole-body retention of trivalent chromium was 6.5 times higher than that of hexavalent chromium at 21 days after a single injection. Following multiple doses, approximately nine times more

trivalent chromium was retained than hexavalent chromium (VI). Both were measured by whole-body clearance rates and cumulative total excretion of chromium in urine and feces. Analyses of fecal and urinary excretion confirmed that most of the urinary chromium clearance that occurred soon after injection, and chromium excretion from animals treated with hexavalent chromium was much faster in both urine and feces than from those treated with trivalent chromium. However, the rate of chromium excretion in the urine was greater than that in the feces for both forms of chromium. After administration of a single dose of trivalent chromium, 87% was retained 3 days after treatment, 73% after 7 days, and 45% after 21 days. The high retention rate of trivalent chromium was attributed to its binding to form coordination compounds or polynuclear complexes. By comparison, potassium dichromate showed a much faster removal rate. At 3 days, 31% was retained, 16% at 72 days, and only 7.5% at 21 days. The low initial retention of hexavalent chromium ion is attributed to its low ability to form co-ordination compounds at physiological pH. Most of the hexavalent chromium is excreted in the urine, but the chromium remaining in the peritoneal cavity would be expected to be reduced from hexavalent to trivalent in a few hours and then to be released by the trivalent chromium mechanism. Similar retention rates were observed when chromium was administered repeatedly to mice.

The toxicokinetics of hexavalent chromium was studied in the rat after intratracheal administration of chromates of different solubilities (Bragt and van Dura, 1983). After a single intratracheal dose of radiolabeled sodium zinc, or lead chromate, sodium chromate and less soluble zinc chromate were absorbed into the blood, resulting in increased excretion of chromium into the urine. The maximum blood chromium level from sodium chromate was  $0.35 \mu\text{g Cr}/\text{ml}$  at 30 minutes after intratracheal administration. Zinc and lead chromates showed maximum levels of 0.60 and  $0.007 \mu\text{g Cr}/\text{ml}$  respectively, at 24 hours. The cumulative excretion of radiolabeled chromium in urine up to 10 days after dosing was about 25% and 20% of the administered dose for the zinc and sodium chromates, respectively. Only about 2% of administered lead chromate was excreted in the urine within 10 days. The more insoluble a chromate was in water, the higher its elimination in the feces. For example, the cumulative excretion in feces was almost 80% of the administered dose of lead chromate for up to 10 days after dosing. Chromium was retained in the spleen and bone marrow at higher levels than in blood for all three chromates. For sodium chromate, the levels in the kidneys and liver were also significantly higher than in blood. The authors suggested that biological monitoring of chromium in urine and blood of workers dealing with



lead chromate is not indicative of previous exposure because of the possibility of minor resorption of lead chromate.

A study (reported as an abstract) of the levels of welding fume components in various bodily tissues and fluids of rats was done to demonstrate the physical-chemical differences between fumes generated in MMA and MIG welding (Aitio, 1985). After exposure to MIG welding fumes, chromium and iron were cleared very slowly from the lungs, and even nickel and manganese disappeared slowly, with half-times of 85 and 125 days, respectively. In contrast, after exposure to MMA welding fumes, some nickel and chromium disappeared from rat lungs immediately after exposure, followed a second, slower phase of disappearance with half-times of 40 and 20 days for nickel and chromium, respectively. Urinary excretion rates for chromium after exposure to MMA welding fumes corroborated the biphasic rate of disappearance and suggested that there may be accumulation of chromium in the body during the working week.

For humans, Aitio (1985) reported that data on kinetics of nickel and manganese after exposure to different welding fumes are lacking. There appeared to be increased urinary excretion of both after MMA welding, but for MIG welders, there was no increased urinary excretion of nickel, and there were no data for manganese.

All metal components of welding fumes were known to accumulate in the lungs, according to Aitio (1985). However, little is known about the metal contents of other tissues in welders. The concentration of chromium increased five-fold in the liver and kidney of rats exposed to MMA welding fumes, but the concentration of nickel did not increase. No increases were detected in either chromium or nickel levels in rat brain.

**3.1.4 Retention and Clearances.** Several studies have been reported recently by Kalliomäki and coworkers on the retention and clearance of different forms of welding fumes in rats (Lakomaa et al., 1982; Kalliomäki et al., 1982; Kalliomäki et al., 1983a; Kalliomäki et al., 1983b; Kalliomäki et al., 1983c; Kalliomäki et al., 1983d; and Anttila et al., 1985). In general alveolar retention of fume particles from stainless steel MMA welding is greater than from mild steel MMA welding.

For example, Kalliomäki et al. (1983a) compared the retention and clearance of MMA/SS and MMA/MS welding fumes in rats. In this study, rats were exposed to 43 mg/m<sup>3</sup> of either of the two types of welding fumes by inhalation using a "nose-only" exposure chamber. For MMA/SS welding fumes, the concentrations for Cr, Ni, and Fe (exogenous) in the lungs correlated well ( $p < 0.001$ ) with cumulative duration of exposure, showing a linear retention of these elements up to 20 days. The retention of Mn became saturated after 19 hours of

exposure and was low in comparison with the other elements. The biological half-times for lung clearance were 30 to 50 days for these elements, indicating a quite slow clearance mechanism after exposure to MMA/SS welding fumes.

In contrast, the retention rate of Fe (exogenous) found for exposure to MMA/MS welding fumes was rapid (28 µg/h) during the first 10 days of exposure, but thereafter, the concentration saturated. The concentration of Mn also saturated during the first five days of exposure. The lung clearance patterns of Fe (exogenous) and Mn were also different from those observed for MMA/SS welding fume exposure. Biological half-times of clearance were 6 and 0.5 days for Fe (exogenous) and Mn, respectively, indicating rapid clearance.

In summary, after four weeks of exposure, the maximum alveolar retention of MMA/SS welding fume particles was about four times higher than retention of MMA/MS particles in rats. This finding apparently agrees with earlier observations made in welders. Total iron concentration in the lungs of rats exposed to MMA/MS welding fumes was two times higher than that in unexposed rats. In contrast, MMA/SS welding fumes did not significantly affect total iron concentration. Clearance of MMA/MS welding fume particles was much more rapid than that of MMA/SS particles.

## 3.2 In Vitro Studies

**3.2.1 Mutagenesis Assays.** Previous studies testing MIG/SS or MMA/SS welding fumes in the Ames *Salmonella typhimurium* assay have identified the hexavalent form of chromium as the active mutagen. It has been reported that hexavalent chromium is not stable in MIG/SS fumes but decays rapidly, defying standard collection methods so that measures of the mutagenicity of fumes experienced by welders in an occupational setting are likely to be inaccurate (Stern, 1983).

For this reason, Stern (1983) investigated the possibility of using a modification of the Ames *S. typhimurium* assay to evaluate fumes from MIG/SS welding. MIG/SS and MMA/SS fumes were generated by a reference welding robot and either collect for analysis or passed through an impinger system designed to collect fresh fumes that would theoretically mimic the actual fumes to which welders are exposed during work. Fumes were routinely analyzed for water-soluble and -insoluble fractions of iron and chromium. The hexavalent form of chromium was analyzed using atomic absorption spectrometry. Strain TA100 cells growing in suspension without a metabolic activation system were placed in a single impinger system producing MIG/SS fumes. They were exposed for durations varying from 200 seconds to 3600 seconds, in 200-second intervals, during which time

a maximum of 4.8 mg of fume was collected; the cells were then plated for mutagenicity and survival. Cell toxicity increased with exposure, but a concentration-related significant increase in the number of histidine revertants per plate was observed. The investigator suggested that, for the purposes of assessing health risks from welding fumes, the potency of hexavalent chromium component found in welding fumes is identical on an equimolar basis to that of hexavalent chromium from other sources. Although the methods used in this assay are a departure from the standard assay protocol, the results are generally in agreement with the results of other researchers who have used the standard plate-incorporation method (Stern et al., 1982; Reuzel et al., 1985).

**3.2.2 Cell Transformation Assays.** Hansen and Stern (1983, 1985) studied the ability of nickel components of MIG welding fumes to transform baby hamster kidney cells (BHK-21) and Syrian hamster embryo (SHE) cells in culture. These assay systems were modified from standard assay protocol, although the modifications were not specified. This protocol was chosen so that transformation rates due to the presence of nickel compounds in the MIG/SS welding fumes could be compared with the transformation rates of nickel subsulfide (a known animal carcinogen), two different nickel oxides, and corundum on an equally toxic basis. This modification was based on the assumptions that only nickel taken up by the cells would be toxic, that the toxicity of these materials in transformation assays is a direct measure of available nickel, and that nickel is the ultimate carcinogen independent of the uptake mechanism. Hansen and Stern observed that the transformation frequencies at the 50% survival level were identical, suggesting to them that the nickel component of all the compounds was responsible for both their toxicity and their transforming ability.

In a study using the same modified protocol, MMA/SS welding fumes were evaluated (Hansen and Stern, 1985). Apparently, the water-soluble component, hexavalent chromium, was the active compound in transforming BHK-21 and SHE cells. Trivalent chromium compounds were not active, nor were mild steel welding fume particles. In a further modification of this assay system, growing BHK-21 and SHE cells were exposed to fresh welding fumes via a water impinger system used for collection of fresh fumes. By this method, Hansen and Stern were able to demonstrate the presence of a short-lived, biologically reactive species that is not typically collected and cannot be assayed in fumes obtained by standard monitoring techniques. In this system, soluble chromium compounds were toxic at 1 to 2  $\mu\text{g}/\text{ml}$ , whereas soluble nickel compounds were toxic as 75  $\mu\text{g}/\text{ml}$ .

It should be noted that these results were obtained through a modification of the standard *in vitro* BHK-21 SHE cell transformation assays that has not been validated by other researchers.

**3.2.3 Cytogenetic Assays.** MMA/SS welding fumes were found to induce sister chromatid exchanges (SCEs) *in vitro* in Chinese hamster ovary (CHO) cells (Reuzel et al., 1985). Potassium chromate, when tested in the same system, was similar in potency to MMA/SS welding fumes, but MIG/SS welding fumes were negative in this system. No further details using this assay were reported in the meeting abstract that was available for this review.

No significant increase in the frequency of chromosome aberrations (CAs) and SCEs was observed in the peripheral lymphocytes of 24 male MMA/SS workers from six industries in different parts of Sweden, when compared with controls (Littorin et al., 1983). Controls were matched for sex, age, smoking and drug consumption history, socioeconomic status, and living area. The test subjects were chosen for their long experience (median 19 years, range 7 to 41 years) with stainless steel welding. Exposure to welding fumes during the sampling period was confirmed by (1) counting the number of electrodes used during the work day, (2) measuring the chromium in workplace air, and (3) measuring chromium levels in urine collected during the work day.

In contrast, there was a statistically significant ( $p < 0.007$ ) increase in frequency of the number of certain types of CAs (interchanges, dicentric, ring chromosomes, and marker chromosomes) of smokers compared with nonsmokers plus exsmokers. The frequency of other types of CAs did not differ, nor did the total number CAs and micronuclei or the frequency of SCEs. However, negative results in this assay system may not be relevant to the question of the genotoxicity of welding fumes in man. Husgafvel-Pursiainen et al. (1982, 1983) conducted a similar study of CAs and SCAs in the peripheral lymphocytes of 23 MMA/SS welders from three different companies in Finland. These welders were selected because they had been exposed almost exclusively to MMA/SS welding fumes in the preceding 10 years (median length of employment in welding was  $21 \pm 10$  years). Exposure to welding fumes at the time of the blood sampling was confirmed by urine samples that were taken at the end of the work day and analyzed for chromium and nickel; a personal and medical history was recorded for each welder and control. The urine levels of chromium for some of the welders exceeded the standard (0.6  $\mu\text{mole}/\text{l}$ ) for exposure recommended in Finland. Nevertheless, no significant difference was observed, in either CAs or SCEs in the blood of welders and controls. These negative findings could not be attributed to lack of exposure to welding fumes; however,

peripheral lymphocytes may not be the appropriate target site for measuring genotoxic effects of exposure. As has been observed elsewhere, there was a significant ( $p < 0.01$ ) positive association between smoking and SCE frequency within both the welder group and the control group.

**3.2.4 In Vitro Toxicity Assays.** The possibility of using bovine alveolar macrophages in culture to measure the potential inhalational toxicity of welding fumes has been investigated in two preliminary studies (Hooftman et al., 1985, and White et al., 1983), since alveolar macrophages have been shown to be important in the lung's ability to detoxify inhaled particles.

In the study of White et al. (1983), welding particles were obtained from three sources: stainless steel welding with a rutile-basic-coated electrode, mild steel welding with a basic-coated electrode, and mild steel welding with a rutile-coated electrode. The chemical compositions of the particles were analyzed so that chromium salt solutions could be made up to concentrations equivalent to the hexavalent chromium in the welding fumes. Titanium dioxide and chrysotile asbestos were negative and positive controls, respectively. Alveolar macrophages were harvested and welding fume particles, trivalent and hexavalent chromium salts, titanium dioxide particles, or chrysotile asbestos fibers were cultured with the cells for 17 hours in serum-free medium. Toxicity was measured by cell detachment and trypan blue exclusion.

In cultures exposed to welding fume particles, detachment increased with dose; at the highest tested dose (40 mg/ml), about 95% of the cells were detached. A high percentage of cells were nonviable by trypan blue exclusion, in ratios roughly proportional to dose. Welding fumes from mild steel rutile-coated electrodes were the least toxic, and stainless steel welding fumes obtained from rutile-basic-coated electrodes were the most toxic, by both tests. Hexavalent chromium, in equimolar concentrations to those in the stainless steel, was less toxic than the whole particulate, but trivalent chromium was nontoxic at equimolar concentrations. Therefore, it is possible that compounds other than hexavalent chromium could be contributing to the toxicity of these welding fumes.

In additional studies, decreased toxicity was observed when the culture medium was supplemented with 10% newborn-calf serum, but not when bovine serum albumin was added to the medium. When the main constituent of pulmonary surfactant, dipalmitoyl phosphatidylcholine (DPPC), was added to samples in serum-free medium, welding fume particles tended to aggregate, making toxicity difficult to assess. However, it was observed that DPPC did not affect the toxicity of either hexavalent chromium or the stainless steel rutile-basic-coated elec-

trode welding particles, but did reduce the toxicity of both chrysotile asbestos fibers and mild steel rutile-coated electrode welding particles.

The study of Hooftman et al. (1985) confirmed that hexavalent chromium at concentrations greater than 0.03  $\mu\text{g}/\text{ml}$ , but not trivalent chromium, was toxic to alveolar macrophages in culture. Although experimental details were not reported in this abstract, the authors stated that particles from MMA/SS welding fumes were the most toxic, and that hexavalent chromium toxicity was comparable on an equimolar basis.

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