V. BASIS FOR THE STANDARD

A. Introduction

This chapter summarizes the studies used by NIOSH to form the basis of its recommended standard for welding, brazing, and thermal cutting. NIOSH believes that the studies discussed here provide the best available evidence of the association between adverse health effects and welding. The results of these studies are summarized briefly in the following subsection; they are described and fully referenced later in the chapter.

B. Summary

Analysis of data obtained from welders reveals several types of adverse effects associated with various welding processes. The respiratory system is the primary target of injury. Metal fume fever and pneumonitis are the most common acute respiratory diseases associated with welding as a result of short-term exposures to high concentrations of fumes and gases. Chronic respiratory diseases such as cancer, pneumoconiosis, and bronchitis have been observed among welders exposed to welding fumes and gases (and possibly to asbestos in some instances over long periods). In addition to respiratory diseases, cancers of the kidney, and other urinary tract organs, and the subglottic area of the larynx have been described in such workers. Other health effects and injuries reported include cardiovascular and gastrointestinal diseases, skin sensitization, hearing loss, and eye and musculoskeletal injury. Some evidence indicates a possible relationship between adverse reproductive outcomes and exposure to welding fumes. Because of the diversity of welding techniques, processes, and materials used, most of these studies lack sufficient information to associate a specific chemical or physical agent with a particular health effect.

C. Malignant Diseases

1. Lung Cancer--Epidemiologic Studies

a. Exposure to Fumes from Welding on Stainless Steel and Other Metal Alloys

Statistically significant increases in the rates of lung cancer have occurred among welders exposed to fumes and gases generated from welding on stainless steel [Sjogren 1980; Gerin et al. 1984; Sjogren et al. 1987] and other metal alloys [Breslow et al. 1954; HMSO 1978; Beaumont and Weiss 1981; Milham 1983; Steenland et al. 1986; Schoenberg et al. 1987]. In four of these studies, exposure-response relationships were demonstrated [Sjogren 1980; Beaumont and Weiss 1981; Gerin et al. 1984; Schoenberg et al. 1987].

Steenland et al. [1986] and Sjogren et al. [1987] reaffirmed the excess lung cancer risk when they reanalyzed the studies by Beaumont and Weiss [1981] and Sjogren [1980], respectively.

Beaumont and Weiss [1981] reported excess cancer rates that increased with the duration of welding exposure and the length of time from onset of first exposure. A standard mortality ratio (SMR) of 132 ($p=0.06$) was observed for deaths from lung cancer among welders compared with those for U.S. white males. The SMR for deaths from lung cancer was 174 ($p<0.001$) when calculated on the basis of deaths that occurred 20 or more years after first welding exposure or initial employment as a welder. This study cohort was reanalyzed by Steenland et al. [1986] using an internal comparison group who more closely matched the lifestyles (e.g., smoking habits) of the welders and who were potentially exposed to the same occupational hazards (e.g., asbestos). The lung cancer risk remained statistically significant, with an OR of 152 ($p=0.03$) when duration of exposure was measured using the year the worker was first employed as a welder. An OR of 1.29 ($p=0.03$) for lung cancer was also observed for welders as a function of increasing cumulative exposure.

Two studies [Sjogren 1980; Gerin et al. 1984] reported increased incidences of lung cancer among welders who were exposed to stainless steel welding fumes that contained nickel and chromium. Sjogren [1980] reported an OR of 4.4 ($p<0.03$), and Gerin et al. [1984] found an OR of 3.3 (95% CI=1.2 to 9.2) among another group of stainless steel welders. Deaths from lung cancer remained statistically significant in both studies after adjustment for smoking habits. Although no exposure data were available for either study, measurements of airborne chromium were taken by Sjogren [1980] at similar stainless steel welding sites. They revealed median TWA chromium (trivalent and hexavalent) concentrations of 210 g/m^3 during welding with covered electrodes and 20 μg/m^3 during gas-shielded welding.

Sjogren et al. [1987] reported on a reanalysis of these stainless steel welders [Sjogren 1980] to determine lung cancer risk after 7 years of additional followup. The lung cancer risk remained high for the stainless steel welders, who had an SMR of 249 when their death rates were compared with national death rates. This cohort was also compared with another group of welders who did not weld on stainless steel but were exposed to low concentrations of chromium. These welders had a relative risk of 7.01 (95% CI=1.32 to 37.3) for lung cancer compared with stainless steel welders, which suggests that emissions typically produced during the welding of stainless steel (e.g., chromium, nickel) may be associated with excess lung cancer risk.

b. Exposure to Welding Fumes in General

Studies reported by Breslow et al. [1954], HMSO [1978], Milham [1983], and Schoenberg et al. [1987], provide evidence of an association between exposure to various compositions of welding fumes and gases and an increased risk of lung cancer. A statistically significant ($p<0.05$) OR of 1.56 was reported by Breslow et al. [1954] in a case control study of 518 lung cancer patients that included 10 welders and 4 sheet metal workers exposed to welding fumes. The OR remained statistically significant after adjustment for smoking habits.

Milham [1983] reported on the proportional mortality of lung cancer among welders and flame cutters employed in the State of Washington. The study used death certificates collected over a 29-year period; proportional mortality ratios (PMRs) were determined at 10-year intervals. A statistically significant ($p<0.01$) PMR of 136 was observed for the period 1970-79, and a PMR of 135 ($p<0.01$) was observed for the total study period (1950-79). In another study [HMSO 1978], statistically significant ($p<0.01$) SMRs of 151 (not controlled for smoking) and of 116 (controlled for smoking) were found for a group of workers classified as "gas and electric welders, cutters, and braziers." The study cohort was made up of workers employed in different industries and potentially exposed to various compositions of fumes and gases.

A study of welders in the Louisiana petroleum industry also showed a statistically significant lung cancer risk [Gottlieb 1980]. However, when the cohort was adjusted for age, the OR was no longer statistically significant.

Although an increased risk of lung cancer was found for welders in these studies [Breslow et al. 1954; HMSO 1978; Gottlieb 1980; Milham 1983], the absence of specific exposure information, type of welding performed, and possible concomitant exposures (e.g., asbestos) makes it difficult to associate exposure with the risk of lung cancer. However, in a case control study reported by Schoenberg et al. [1987], shipyard welders had a statistically significant increase in the rate of lung cancer, with an OR of 3.8 (95% CI=1.8 to 7.8). This risk remained high after adjustment for smoking and exposure to asbestos. Of the 33 cases and 18 controls classified as welders, 16 cases and 7 controls were reported to have been exposed to asbestos. The remaining 17 cases and 11 controls who had no reported asbestos exposure, showed an increased smoking-adjusted OR of 2.5 (95% CI=1.1 to 5.5).

Four other mortality studies [Puntoni et al. 1979; Polednak 1981; Becker et al. 1985; Newhouse et al. 1985] reported increased risks for lung cancer among male welders. Although the increases were not statistically significant, the studies collectively demonstrate the possible association between classification as a welder and an increased risk of developing lung cancer. Two of the four studies were conducted on white males who worked as welders at nuclear facilities [Polednak 1981] or at sanitary installations and power plants [Becker et al. 1985].

The larger of those studies [Becker et al. 1985] revealed an OR of 2.4 ($p<0.05$) for all cancers and an elevated OR of 1.7 ($p>0.05$) for cancer of the trachea, bronchus, and lung when compared with a control group that was not exposed to welding fumes. When an external analysis was performed (i.e., comparison with the German national death rates), SMRs for deaths from malignant neoplasms and lung cancer were not markedly increased over the general population. However, when welders were analyzed by 10-year intervals since first exposure, an upward trend in SMRs was observed. The incidence of malignant neoplasms was statistically significant ($p<0.05$) only for the last interval ($\geq$ 30 years since first exposure).

In the smaller cohort study [Polednak 1981], welders were analyzed according to their potential exposure to nickel oxides. Increased SMRs were observed for lung cancer deaths among both exposed (SMR=124) and unexposed (SMR=175) welders. The SMRs were not statistically significant when compared with death rates for U.S. white males. The welders who were not exposed to nickel oxides had a prevalence of smoking that was 2.5 times that of the exposed group. The difference in smoking habits and the fact that the study groups were small (N=536 exposed, N=523 unexposed) contribute to uncertainty in the interpretation of the results. Although the SMRs did not reach statistical significance, the risk of death from lung cancer increased among both groups of welders with increasing years of exposure to welding fumes and gases.

Studies of welders in shipyards [Puntoni et al. 1979; Newhouse et al. 1985] demonstrate an increased risk of lung cancer. Although neither study showed statistically significant increases, Puntoni et al. [1979] found elevated ORs for lung cancer in gas welders (OR=2.12) and electric welders (OR=2.54) when compared with the male staff of a local hospital. An elevated OR of 1.25 for gas welders and an OR of 1.60 for electric welders were observed when the groups were compared with the male population of Genoa, Italy.

Newhouse et al. [1985] found an elevated SMR of 113 for deaths from lung cancer among a group of welders who performed various welding tasks during ship repair. Latency and duration of employment were not analyzed in either study, and no attempt was made to account for the confounding exposure of asbestos.

2. Other Cancer--Epidemiologic Studies

Several studies indicate a possible association between classification as a welder and an increased risk of cancer of the larynx [Olsen et al. 1984] and of the kidney or other urinary tract organs [Puntoni et al. 1979; Milham 1983; Becker et al. 1985]. Skin cancer has also been reported among welders employed for more than 30 years in this occupation [Roquet-Doffiny et al. 1977].

A case-control study conducted by Olsen et al. [1984] reported an unusually high risk of cancer (OR=6.3) of the subglottic area of the larynx among 271 cancer patients who had been occupationally exposed to welding fumes and gases. The high OR for this type of cancer persisted after adjustment for tobacco and alcohol use, but it was not high for those patients (N=12) reported to have been exposed to fumes from stainless steel welding. Other epidemiologic studies [Dunn and Weir 1968; Ott et al. 1976; HMSO 1978; Puntoni et al. 1979; Sjogren 1980; Polednak 1981; Milham 1983] revealed no elevated risk of larynx cancer.

Several cohort mortality studies [Puntoni et al. 1979; Milham 1983; Becker et al. 1985] have reported increased incidences of kidney or other urinary tract cancers among welders. The study of shipyard workers by Puntoni et al. [1979] reported ORs of 5.06 ($p<0.05$) and 5.88 ($p<0.05$) for cancer of the kidney and other urinary tract organs in gas welders compared with two different external control populations. Elevated but statistically insignificant ORs were also reported for electric arc welders. An increased risk of kidney cancer was also noted by Milham [1983] in welders and flame cutters (PMR=182, $p<0.01$), and Becker et al. [1985] reported a statistically significant ($p<0.002$) OR of 15.0 (3 observed versus 0.2 expected) for kidney and other urinary tract cancers among welders. No exposure data were reported in any of the three studies, but Becker et al. [1985] reported that most of the welders in his study performed arc welding with coated chromium-nickel alloy electrodes. Although these studies associated classification as a welder with an increased risk of dying from kidney or other urinary tract cancers, other mortality studies [Dunn and Weir 1968; Ott et al. 1976; HMSO 1978; Polednak 1981; Newhouse et al. 1985] indicated no increased incidences of death from these causes.

3. Toxicological Evidence

The risk of cancer noted among welders is consistent with the findings of in vitro and in vivo mutagenesis assays that have demonstrated various mutagenic potentials for welding fumes, depending on their composition [Hedenstedt et al. 1977; Koshi 1979; Stern et al. 1982; Pedersen et al. 1983]. Results of assays have shown that most of the mutagenic activity of stainless steel welding fumes can be ascribed to chromium(VI) in the water-soluble fraction [Stern et al. 1982]. Maxild et al. [1978] reported that shielded metal arc welding of stainless steel produces 3 to 6 times more fumes (per mass of weld metal) than gas metal arc welding. When the mutagenic potentials for shielded metal and gas metal arc fumes were compared on an equivalent chromium(VI) basis, gas metal arc welding fumes produced four times more mutations in bacteria than shielded metal arc welding fumes [Stern et al. 1982]. Other data reported by Hedenstedt et al. [1977] and Stern et al. [1982] suggest that compounds other than chromium(VI) may be active in the water-soluble fractions of fumes generated from shielded or gas metal arc welding of stainless steel. When water-soluble fractions of both fumes were tested in an assay using metabolically activated S. typhimurium, arc welding fumes were less mutagenic.

In a 2-year study reported by Reuzel et al. [1986], evidence of carcinogenicity was found in animals exposed to stainless steel fumes. Syrian golden hamsters were intratracheally injected with saline suspensions of stainless steel fumes from shielded metal arc welding. One lung cancer resulted from each of two dose groups. No cancers were observed in the untreated control groups or in animals treated with gas metal arc fumes, calcium chromate (positive control), or saline. Because these tumors are extremely rare in Syrian golden hamsters, the authors concluded that the lung tumors were induced by welding fumes.

D. Other Diseases

1. Acute Respiratory Diseases

a. Epidemiological Studies

One of the more frequently reported health effects from exposure to welding fumes is metal fume fever, which often resembles an upper respiratory infection such as influenza, acute bronchitis, pneumonia, or upper gastrointestinal infections [Papp 1968]. These conditions usually last 6 to 24 hr and are often accompanied by chills, trembling, nausea, and vomiting [Rohrs 1957]. Exposure to specific metals such as zinc in zinc oxide fumes [Drinker 1922; Drinker et al. 1927] and to fumes of mixed composition [Ross 1974; Johnson and Kilburn 1983] have been associated with metal fume fever. Although no specific exposure concentrations have been associated with metal fume fever, most reported cases have occurred in workers exposed to welding fumes while working in confined or other poorly ventilated spaces.

Pneumonitis and pulmonary edema have been reported in welders who performed various welding processes (e.g., gas and shielded metal arc welding, silver brazing, or oxyacetylene welding) and were exposed over short periods to high concentrations of nitrogen dioxide [Maddock 1970; Mangold and Beckett 1971], ozone [Molos and Collin 1957; Kleinfeld et al. 1957; Challen et al. 1958], cadmium fumes [Patwardhan and Finckh 1976; Blejer and Caplan 1969; Townshend 1968], chromium and nickel fumes [Jindrichova 1976], or aluminum and iron oxide fumes [Herbert et al. 1982]. Cases of acute cadmium fume pneumonitis and death have been reported among welders exposed either by brazing with silver-cadmium alloy or by cutting or welding cadmium-coated metal in poorly ventilated areas [Christensen and Olson 1957; Beton et al. 1966; Patwardhan and Finckh 1976]. Beton et al. [1966] reported on the death of a welder who was cutting cadmium-plated bolts with an oxyacetylene torch. Based on the amount of cadmium oxide found in the welder's lung during a postmortem examination, the authors estimated that his exposure to cadmium oxide averaged 8.6 mg/m^3. Several other fatalities have resulted from pulmonary edema in welders exposed to nitrogen dioxide concentrations above 100 ppm [Maddock 1970].

b. Toxicological Evidence

Pathological lung changes observed in welders acutely exposed to welding fumes and gases have also been documented in exposed animals [Titus et al. 1935; Kawada and Iwano 1964; Hewitt and Hicks 1973].

Animals exposed to welding fumes and gases for short periods suffered severe lung damage (e.g., edema, hemorrhage, pneumonia, and atelectasis) and death. In one experimental study [Titus et al. 1935], cats and rabbits were exposed to iron oxide fumes for up to 8.5 hr at concentrations of 10 to 350 mg/m^3. All animals developed pulmonary edema. Their alveoli became dilated, their lungs hemorrhaged, and several died. Similar results were reported by Hewitt and Hicks [1973] in albino rats exposed to rutile welding fumes and gases at an average concentration of 1,500 mg/m^3. Rats exposed for either 30 min or 4 hr demonstrated a statistically significant ($p<0.05$) increase in uptake of chromium and antimony by the lungs, and of cobalt by the liver and blood. Microscopic examination of the lungs revealed peribronchial edema and large numbers of particulate-laden macrophages in the alveoli and alveolar ducts. Histopathological lung changes were reversed following 75 days with no exposure; only the particulate material remained within the macrophages.

Pulmonary deposition and clearance rates in animals exposed to fumes from welding nonstainless and stainless steels were investigated by McCord et al. [1941] and Byczkowski et al. [1970]. The rates of metal deposition in the lungs were proportional to the metal content of the emissions; these rates increased in animals that exercised during exposure.

2. Chronic Respiratory Diseases

a. Epidemiologic Studies

Pneumoconiosis, including siderosis, has been reported among welders exposed to iron oxide fumes from bare metal electrodes [Britton and Walsh 1940; Sander 1944; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950]. Although quantitative data on exposures are lacking for most of these studies, Dreesen et al. [1947] provide some data on the extent of exposures before 1950. Samples collected during arc welding of mild steel in a shipyard revealed iron oxide concentrations above 30 mg/m^3 and zinc oxide concentrations above 15 mg/m^3. The highest exposure concentrations were found in poorly ventilated work areas. Approximately 50% of the samples contained less than 5 ppm oxides of nitrogen, and 10% of the samples exceeded 25 ppm.

Other studies have described siderosis complicated by fibrosis [Marchand et al. 1964; Meyer et al. 1967; Stettler et al. 1977; Kleinfeld et al. 1969; Brun 1972; Levy and Margolis 1974; Attfield and Ross 1978]. These findings appear to be associated with the replacement of bare metal electrodes by covered electrodes. Clinical evaluations were made of workers who were exposed to iron oxides and silica and who welded both ferrous and nonferrous materials using covered electrodes. These evaluations revealed diffuse interstitial fibrosis [Meyer et al. 1967] and siderosilicosis [Levy and Margolis 1974]. Levy and Margolis [1974] reported peak airborne concentrations of 19.4 mg/m^3 for iron oxide and 6.82 mg/m^3 for respirable silica among steel foundry welders who had evidence of siderosilicosis.

Welders have also shown decrements in pulmonary function [Hunnicutt et al. 1964; Fogh et al. 1969; Keimig et al. 1983; Oleru and Ademiluyi 1987] and increases in the prevalence of chronic bronchitis [Kujawska 1968; Fogh et al. 1969; Barhad et al. 1975; Antti-Poika et al. 1977; Akbarkhanzadeh 1980; Sjogren and Ulfvarson 1985]. The only exposure data reported are those cited in the studies by Barhad et al. [1975], Sjogren and Ulfvarson [1985], and Keimig et al. [1983]. Barhad et al. [1975] reported that shipyard welders were exposed to total fume concentrations of 6 to 36 mg/m^3 in open work areas and 48 to 92 mg/m^3 in confined spaces during arc welding with covered electrodes. Oxides of nitrogen averaged concentrations of 1.7 mg/m^3 during shielded arc welding and 1.1 mg/m^3 during arc welding. Regardless of the welding process, carbon monoxide concentrations ranged from 6.3 to 17 mg/m^3. In the study by Sjogren and Ulfvarson [1985], exposures to ozone exceeded 0.1 ppm in 50% of the samples collected during gas metal arc welding of aluminum. During stainless steel welding with covered electrodes, 80% of the chromium(VI) concentrations exceeded 20 ug/m^3. Concentrations of nitrogen oxides were less than 5 ppm for all welding processes [Sjogren and Ulfvarson 1985]. Breathing zone air samples collected near welders at the time of the study reported by Keimig et al. [1983] indicated iron oxide concentrations of 1.3 to 8.5 mg/m^3, with no detectable amounts of chromium, copper, fluoride, or lead in any of the air samples.

The cross-sectional study reported by Keimig et al. [1983] found that welders and controls who smoked had higher frequencies of reported respiratory symptoms (e.g., bronchitis, pneumonia, and cough) than corresponding nonsmokers. Although welders who did not smoke reported higher frequencies of symptoms than nonsmoking controls, the differences were statistically significant ($p<0.05$) only for the symptoms of increased phlegm and episodes of cough and phlegm. The only statistically significant differences noted in pulmonary function tests were decreases in forced vital capacity (FVC) at the end of the work shift for nonsmoking welders, nonsmoking controls, and smoking controls.

Similar findings were reported by Oleru and Ademiluyi [1987] for a group of workers engaged in the welding of medium- and high-alloy steel. Although no evidence of obstructive lung disease was found, 7 of 67 persons tested had restrictive lung impairment. Welders given pulmonary function tests to assess the effects of exposure over a 40-hr work week demonstrated statistically significant ($p<0.05$) decrements in all parameters measured. Peak flow measurements made on this group after an 8-hr work shift showed acute changes in pulmonary function that were statistically significant ($p<0.05$). However, these changes were not statistically significant when the group was retested after 3 additional days of welding. In the studies by Hunnicutt et al. [1964], Fogh et al. [1969], and Akbarkhanzadeh [1980], the increased prevalence in decrements of pulmonary function or chronic bronchitis were observed only in welders who smoked.

b. Toxicological Evidence

Siderosis has been produced by exposing animals to mixed compositions of fumes [McCord et al. 1941; Garnuszewski and Dobrzynski 1966]. All rats and rabbits developed siderosis when they were exposed to shielded metal arc welding fumes for 6 hr/day, 5 days/week for 46 days followed by an additional 43 days without exposure [McCord et al. 1941]. Animals were exposed to average concentrations of 465 mg/m^3 (ferric oxide), 61 mg/m^3 (silicon dioxide), and 16 mg/m^3 (manganese). Similar results were produced by Garnuszewski and Dobrzynski [1966], who exposed groups of guinea pigs and rabbits to fumes that were either high in silicon oxide (25.5%) and low in ferric oxide (18%), or low in silicon oxide (7.8%) and high in ferric oxide (23%). Each experimental group of animals was subdivided into a high-exposure group (36 mg of total fumes/m^3 of air) or low-exposure group (18 mg of total fumes/m^3 of air). All animals were exposed 4 hr/day, 6 days/week for 110 days. All exposed guinea pigs developed a mixed type of pneumoconiosis (e.g., siderosis with silicosis manifested by pneumoconiotic nodules containing collagenous fibers and silica particles). No pneumoconiosis was observed in the exposed rabbits.

3. Other Adverse Health Effects

a. Auditory Impairment

Auditory impairment has been reported among welders as a result of traumatic injury [Frenkiel and Alberti 1977] or excessive sound pressure [Hickish and Challen 1963; Bell 1976]. Several cases of eardrum injury and permanent hearing loss were reported by Frenkiel and Alberti [1977] among welders who did not wear ear protection and were injured by sparks and molten metal that entered the ear while welding. Studies conducted by Hickish and Challen [1963] and Bell [1976] described the risk of noise-induced hearing loss in welders performing arc air gouging or plasma torch welding of metals. Mean temporary hearing losses of 19 dB at 4,000 Hz and up to 35 dB at 8,000 Hz were reported by Hickish and Challen [1963] among a group of welders who were performing plasma torch welding for 1 hr without wearing hearing protection.

b. Cardiovascular Disease

Studies that have assessed cardiovascular disease in welders have produced equivocal results. Two mortality studies indicate increased risks of death from cardiovascular disease among shipyard welders [Newhouse et al. 1985; Puntoni et al. 1979]. Newhouse et al. [1985] reported an increased SMR of 130 ($p=0.10$) for ischemic heart disease, and Puntoni et al. [1979] reported ORs greater than 1.00 for cardiovascular disease. Neither study adjusted for smoking habits, and no information was provided on other possible risk factors. Two other studies analyzed deaths from cardiovascular disease: An SMR reported by Polednak [1981] and a PMR by Milham [1983] were both less than 100. Although the association between welding and an increased risk of cardiovascular disease remains equivocal, the data do provide cause for concern.

c. Dermal Effects

Several types of dermal conditions observed in welders have been attributed to exposure to physical agents, including UV radiation [Grimm and Kusnetz 1962; Pattee et al. 1973; Balabanow et al. 1967; Roquet-Doffiny et al. 1977; Ross 1978], IR radiation [Lydahl and Philipson 1984; Moss et al. 1985], and metals to which workers can become sensitized [Kaplan and Zeligman 1963; Fregert and Ovrum 1963; Shelley 1964; Kalliomaki et al. 1977]. Chronic dermatitis and other skin diseases have been documented in several case reports [Shelley 1964; Balabanow et al. 1967; Roquet-Doffiny et al. 1977] that described welders whose skin came into contact with many types of metals (e.g., nickel, cadmium, and chromium) and fluxes. Welders exposed to welding fumes from stainless steel have experienced episodes of facial contact dermatitis [Fregert and Ovrum 1963]. In these cases, removal of the worker from exposure or the use of protective clothing eliminated or greatly minimized the severity of the disorder.

d. Eye Injuries

Welders or others working near welding processes risk eye injury from metal spatter, foreign bodies in the eyes, and exposure to nonionizing electromagnetic radiation [NIOSH 1972a; Marshall et al. 1977; Palmer 1983; BLS 1985]. Exposure to ultraviolet radiation (UV) from welding arcs has caused acute keratoconjunctivitis, also known as welder's flash or actinic ray photokeratitis [Minton 1949; Sykowski 1951]. Repeated episodes of welder's flash over a long period have caused cataracts [Golychev and Nikitina 1974]. Similarly, exposure to infrared radiation (IR) has caused thermal damage to the cornea and aqueous humor of the eye and has been associated with the formation of lenticular cataracts [Palmer 1983]. Such adverse ocular effects have been attributed to the improper use or absence of eye protection [Minton 1949; Sykowski 1951; Entwistle 1964; Karai et al. 1984].

According to Bureau of Labor Statistics (BLS) data for the period 1976-81, eye injury was the type of injury that welders reported most frequently. Such injuries were associated with exposure to radiation or foreign bodies in the eyes among welders and flame cutters [BLS 1985]. These recent data are consistent with earlier data [BLS 1983]. For the 1983 BLS report, data were collected over a 5-month period in 1978 from welders in 18 states (BLS 1983). Sixty-seven percent of the reported injuries were to the eyes. No information was given in either report as to whether eye protection was being worn at the time of the injury.

e. Gastrointestinal Disorders

Gastrointestinal disorders (e.g., nausea, vomiting, and gastrointestinal cramps) are often experienced by welders with metal fume fever, but they are reversible following treatment and removal of the worker from additional exposure [Rohrs 1957; Papp 1968]. Studies by Mignolet [1950], Stancari and Amorati [1963], and Rozera et al. [1966] reported digestive system disorders in welders that included gastritis, gastroduodenitis, and gastroduodenal ulcers. The authors attributed these conditions to long-term exposures to welding fumes and gases. Epidemiological studies of welders conducted by Puntoni et al. [1979], Polednak [1981], Milham [1983], and Becker et al. [1985] found no increases in mortality as a result of diseases of the digestive system.

f. Musculoskeletal Effects

Reports of musculoskeletal injuries involving the shoulders, back, and knees have been noted in several studies of welders [Herberts and Kadefors 1976; Kadefors et al. 1976; Nauwald 1980]. Complaints of shoulder pain and reduced muscle power, particularly of the supraspinatus muscle, have been frequently attributed to overhead welding performed by both inexperienced and experienced welders. Knee joint problems (including fluid sac diseases, arthritis, and proliferation of fatty tissue) have also been observed, primarily in welders with more than 6 years of experience.

g. Reproductive Effects

Studies conducted by Rachootin and Olsen [1983] and Lindbohm et al. [1984] suggest a possible association between adverse reproductive outcomes and the subject's status as a welder or as the wife of a metal plate worker. A statistically significant increase ($p<0.05$) in spontaneous abortions was observed for wives of metal plate workers [Lindbohm et al. 1984]. The authors suggested that this increase was caused by exposure to chromium or nickel. The case-control study by Rachootin and Olsen [1983] indicated a statistically significant increase ($p<0.05$) in delayed conception, with ORs of 1.4 for male welders and 2.4 for female welders. The risk remained statistically significant for women after adjustment for age, smoking habits, alcohol consumption, and past use of oral contraceptives. Men and women assigned to the subgroup "Welding of Stainless Steel" had no statistically significant increase in their risk of delayed conception. Although the studies suggest a reproductive risk, several methodologic problems exist, including the inability to accurately estimate possible exposures based on employment history [Lindbohm et al. 1984; Rachootin and Olsen 1983], the lack of information on smoking habits or alcohol consumption [Lindbohm et al. 1984], and possible data collection biases resulting from the use of self-administered questionnaires [Rachootin and Olsen 1983].

No experimental animal studies have been conducted to determine the effects of welding fumes and gases on the reproductive system.

E. Safety

Fires, explosions, and electric shocks are common welding hazards that have caused many disabling injuries and fatalities [BLS 1985]. Fires caused by the welding flame itself or by flying sparks have been responsible for many injuries and fatalities of welders [NFPA 1977; Buhrer and Brunschwiler 1978]. Injuries have also been reported as a result of accidental fires caused by welding in oxygen-enriched atmospheres in confined spaces or by oxygen leaks from welding tanks [Rames 1976]. Fires and explosions have also been caused by welding or cutting tanks and drums that have not been properly emptied and cleaned of flammable liquids [CDLSR 1975; NFPA 1977].

Electric shocks have occurred in welders using alternating or direct currents of 120 to 600 A at 30 to 60 volts. Even if the shock itself was harmless, resulting falls have caused serious injury or death [Britton and Walsh 1940]. Many of these incidents have occurred from improper grounding of the welding electrode or careless handling and changing of electrodes.

F. Conclusions

Epidemiologic studies and case reports of workers exposed to welding fumes and gases provide adequate evidence that these workers are at an increased risk of contracting acute respiratory diseases such as metal fume fever and pneumonitis [Drinker 1922; Drinker et al. 1927; Christensen and Olson 1957; Kleinfeld et al. 1957; Molos and Collins 1957; Rohrs 1957; Challen et al. 1958; Beton et al. 1966; Papp 1968; Townshend 1968; Blejer and Caplan 1969; Maddock 1970; Mangold and Beckett 1971; Ross 1974; Jindrichova 1976; Patwardhan and Finckh 1976; Herbert 1982; Johnson and Kilburn 1983]. Chronic respiratory diseases such as pneumoconiosis and bronchitis have also been documented in workers exposed to welding emissions [Britton and Walsh 1940; Sander 1944; Dreesen et al. 1947; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950; Hunnicutt et al. 1964; Marchand et al. 1964; Meyer et al. 1967; Kujawska 1968; Fogh et al. 1969; Kleinfeld et al. 1969; Brun et al. 1972; Levy and Margolis 1974; Barhad et al. 1975; Antti-Poika et al. 1977; Stettler et al. 1977; Attfield and Ross 1978; Akbarkhanzadeh 1980; Sjogren and Ulfvarson 1985; Keimig et al. 1986; Oleru and Ademiluyi 1987].

Some studies report that an increased risk of lung cancer is associated with welding on stainless steel [Sjogren 1980; Polednak 1981; Gerin et al. 1984; Sjogren et al. 1987], and the study reported by Polednak [1981] observed an increased risk in welders exposed to nickel oxides. Studies of welders exposed to fumes of mixed composition have also reported an increased risk of lung cancer [Beaumont and Weiss 1981; Breslow et al. 1954; HMSO 1978; Milham 1983; Puntoni et al. 1979; Becker et al. 1985; Newhouse et al. 1985; Steenland et al. 1986; Schoenberg et al. 1987].

An exposure limit for total welding emissions cannot be established because the composition of welding emissions (chemical and physical agents) varies for different welding processes and because the various components of a welding emission may interact to produce adverse health effects, including cancer. Thus even compliance with specific chemical or physical agent exposure limits may not ensure complete protection against an adverse health effect. Therefore, exposures to all chemical and physical agents associated with welding should be reduced to the lowest concentrations technically feasible using current state-of-the-art engineering controls and good work practices. Individual exposure limits for chemical or physical agents are to be considered upper boundaries of exposure.

Equivocal evidence exists to show the effects of welding emissions on (1) the increased risk of cancer at sites other than the lung [Olsen et al. 1984; Puntoni et al. 1979; Milham 1983; Becker et al. 1985; Roquet-Doffiny et al. 1977], (2) the cardiovascular system [Newhouse et al. 1985; Puntoni et al. 1979], and (3) the reproductive system [Rachootin and Olsen 1983; Lindbohm et al. 1984]. However, following the recommendations in this document should prevent or greatly reduce a welder's risk of developing these diseases. Following the recommendations should also reduce injuries and deaths resulting from unsafe work conditions.

VI. HAZARD IDENTIFICATION

A. Workplace Monitoring and Analytical Methods

An occupational health program should include methods for thoroughly identifying and assessing all potential hazards if it is to protect welders from the adverse health effects of chemical and physical agents in their work environment. Information provided by monitoring and analysis is needed to determine whether controls (e.g., engineering controls or protective clothing) are necessary, what types of tests should be conducted in a medical monitoring program, what information should be included in a worker training program, what types of warning signs should be posted, and what types of work practices may be required to protect the health of workers. Routine exposure monitoring is also an important part of this program because it gauges the effectiveness of controls.

1. Airborne Contaminants

Routine air monitoring of the workplace helps to determine whether a worker is exposed to any individual chemical at or above its exposure limit. These data must be obtained for all workers involved in welding activities and for all other persons working near welding sites. If a worker's exposure can be accurately characterized, and if concentrations of specific agents are found to be below their exposure limits (or below their action limits if the agents have established NIOSH RELs), further characterization of the work environment is not needed as long as the process or work conditions do not change. No safe exposure concentration has been established for chemicals that NIOSH has identified as potential occupational carcinogens.

An effective air monitoring program should include the following components to accurately assess each worker's exposure:

- A procedure to assess the worker's potential for exposure. This procedure should include collection of data on the types of materials being used (e.g., welding rods and fluxes) and the composition of the base metals,

- Knowledge of air sampling and analytical method(s) required to determine concentrations of airborne chemical and physical agents, and

- Information on the number of workers potentially exposed and the duration of their exposure.

a. Determining the Potential for Exposure

The first step in determining the potential for exposure to a specific agent is the preparation of a hazard inventory. This inventory should include information on the type of welding process that will be performed, the possible chemical and physical agents that may be encountered, and the composition of the base metal, coatings on the metal, fillers, and fluxes. This initial assessment should include a review of all precautionary labels on containers of filler metals, electrodes, and flux materials and any material safety data sheets. Refer to Chapter III, B (Potential for Exposure) for a more detailed description of contaminants that may be encountered during welding.

After an initial assessment of potential airborne exposures, employers should identify workers whose exposures to a specific agent may be at or above its exposure limit (or action limit if the agent has an established NIOSH REL). To determine which workers may be at increased risk of exposure, the following work conditions should be evaluated: the location of the welding process with respect to the worker(s), frequency of the welding being performed, the use of engineering controls, and the type of work practices employed. If some uncertainty exists about a worker's exposure (regardless of job title), the worker should be included in the air monitoring program, at least initially.

b. Sampling Strategy (Location, Number, and Frequency of Sampling)

The following subsections provide some basic criteria for establishing and implementing a sampling strategy.

(1) Sampling Location

The sampling location is important in achieving an accurate characterization of the suspected exposure. The preferred sampling location is within the breathing zone of the worker and is referred to as a personal sample. The concentration of fumes or gases in the welder's breathing zone for a given process varies depending on the specific work practices of the welder and the type of exhaust ventilation used. For example, if a welder leans over the work, exposure for that worker will be greater than for a welder in an upright position. Moreton et al. [1975] reported that exposure concentrations varied by a factor of six among welders who performed the same task but used different work practices. In addition, the concentration of airborne contaminants typically varies as a function of distance from the worksite. The type of ventilation, convective drafts, and location of the operation further increase the variability of contaminant concentrations with distance from the source.

If personal samples are collected on a worker wearing a welding helmet, the inlet to the sampling device should be correctly positioned within the helmet. The helmet reduces to some degree the amount of contaminant in the breathing zone. Johnson [1959] sampled outside and inside a welding helmet simultaneously during production welding. Concentrations of iron fumes were compared for the two sample locations. The ratio of outside to inside concentrations ranged from 1.03:1 to 7.55:1, with an average of 3.5:1. Based on this and similar experimental studies, the American Welding Society (AWS) Standard F1.1-76, "Method for Sampling Airborne Particulates Generated by Welding and Allied Processes," specifies that air samples should be taken within the welding helmet 50 millimeters (mm) to the left or right of the welder's mouth. In a similar study measuring the performance of full-facepiece respirators, Myers and Hornung [1987] found that sampling errors in the facepiece were minimized by placing the inlet of the sampling probe to within 1/2 to 3/4 inch (in.) of the wearer's mouth.

Because welding emissions often consist of fumes and gases, different sampling media are often required. However, space is restricted in the welding helmet, and wearing several air sampling instruments can cause discomfort. Thus a given worker may have to be monitored over a period of several days, or different types of samples may have to be collected on various workers at the same worksite.

(2) Number of Samples Required

Once the sampling location has been identified, employers should select the number and type of workers to be sampled by considering which workers have the highest potential for exposure and which workers are potentially exposed despite working some distance from the welding process. For a more detailed discussion on the selection of workers and a strategy for sample collection, consult the NIOSH Occupational Exposure Sampling Strategy Manual [Leidel et al. 1977]. This manual also provides guidance on the length of time needed for sample collection, number of samples required for statistical validity, and the scheduling of sample collection (i.e., on one or multiple days) to accurately define workers' exposures.

(3) Sampling Frequency

Unless welding is performed under production-line conditions, sampling should be conducted at frequent intervals to characterize exposures adequately and determine the need for controls. However, when the welding process is repetitive (as it is on a production line), exposure conditions may be characterized and quantified by an initial sampling survey. It can be assumed that conditions will remain relatively constant during future welding activities if there is no change in the process or type of welding. Under these circumstances, routine sampling should not be necessary. This strategy applies only when the survey results indicate that workers are not being exposed to any agent at or above its exposure limit (or action limit if the agent has an established NIOSH REL). With these survey results, no further sampling is necessary as long as no change occurs in the conditions that existed during sampling.

Unfortunately, it is not always possible to note when conditions change. For example, if debris accumulates in the ventilation system, the collection efficiency of the system may decrease, and workers' exposures could increase without any visible signs of change. Although this type of potential problem may not necessitate routine air sample monitoring, it does require periodic examination of the ventilation system to ensure that it is operating at optimum efficiency. If the potential exists for any condition to change (e.g., malfunction of ventilation system) without apparent warning, then a routine monitoring program should be implemented and continued until all such conditions can be standardized. For a more detailed discussion on determining the need for additional sampling, consult the NIOSH Occupational Exposure Sampling Strategy Manual [Leidel et al. 1977].

c. Analytical Methods

Analytical methods for assessing samples of most welding emissions have been developed by NIOSH and are listed in Table VI-1. Methods for monitoring physical agents are presented in Table VI-2.

2. Physical Agent Monitoring

Physical hazards associated with welding include electromagnetic radiation, X-radiation, and noise. The following guidance is provided to assist in the initial assessment of these potential hazards.

a. Monitoring UV Radiation Levels

Quantifying exposure to optical radiation is difficult, and the NIOSH criteria document on radiation [NIOSH 1972b] does not include specific recommendations for monitoring UV radiation. The following guidelines are provided to assist in the recognition and control of any potential exposure to UV radiation.

Many welding processes generate radiation from the entire UV spectrum or from parts of the UV spectrum. Most commercially available UV measuring devices (with the exception of the thermopile) are wavelength selective. Thus measuring a welder's exposures to UV radiation can be difficult. Other problems in accurately measuring worker exposures include measurement errors caused by water vapor in the air, errors caused by the directionality of exposure meters, reflection errors, and equipment problems such as solarization and aging of lenses and other components [NIOSH 1972a].

Table VI-1.--NIOSH analytical methods for chemicals associated with welding processes

Hazard	NIOSH analytical method number[a]
Acetylene	None
Arsenic, inorganic	7900, 7300
Asbestos	7400
Beryllium	7102, 7300
Cadmium	7048, 7300, 7200
Carbon dioxide	S249
Carbon monoxide	S340(4)
Chromium(VI)	7600 (Cr VI); 7024, 7200, 7300 (other chromium)
Cobalt	7027, 7300
Copper fume	7029, 7200, 7300
Fibrous glass	0500, 7400
Fluorides, inorganic	7902
Iron oxide fume	7200, 7300
Lead, inorganic	7082, 7300
Magnesium oxide fume	7200, 7300
Manganese	7200, 7300
Molybdenum	7300
Nickel, inorganic and compounds	7200, 7300
Nitrogen oxides	6700 (NO_2)
Nuisance dust	0500
Ozone	S8, 153, 154
Phosgene	219
Silver	7200, 7300
Tin, inorganic compounds except oxides	7300
Tungsten and cemented tungsten carbide	7074, 7300
Vanadium	7300
Zinc oxide	7502, 0500, 0600, 7030

[a] NIOSH Manual of Analytical Methods [NIOSH 1984].

Table VI-2.--Methods for monitoring physical agents associated with welding processes

Hazard	NIOSH criteria document number*
Hot environments	86-113 (revised) [NIOSH 1986]
Noise	HSM 73-1101 [NIOSH 1972b]
UV radiation	HSM 73-11009 [NIOSH 1972a]

*No NIOSH methods exist for monitoring these physical agents; however, direct-reading instruments may be used to assess workplace exposures, as indicated in NIOSH criteria documents.

Control of UV radiation exposure is best ensured through a management control program that relies on the containment of UV emissions through barriers. Where barriers cannot be used, personal protective devices such as appropriate clothing and barrier creams should be used to protect the skin; proper safety glasses should be worn to protect the eyes.

b. Monitoring X-Radiation

Electron beam welding equipment produces X-rays that are normally contained by the welding chamber. The AWS recommendations outlined in F2.1-78, "Recommended Safe Practice for Electron Beam Welding and Cutting" [AWS 1978], specify that periodic surveys be made to detect any leakage of X-radiation. The electron beam should be grossly unfocused and aimed at a tungsten target. A preliminary assessment of the equipment should be made while it is operating at maximum current and voltage levels to detect leakage. Thereafter, periodic surveys can be made when the equipment is moved or repaired. Film badges or some other means of X-ray exposure monitoring should be provided for equipment operators.

c. Monitoring Noise Levels

Excessive noise may be produced in a number of welding and allied processes including plasma arc, metal spraying, and arc air gouging processes. The potential for a given process to generate excessive noise can quickly be determined using a sound level meter with an A-weighted scale and a type II microphone. However, these meters do not accurately measure impact noise.

Operations that generate significant noise levels during a full work shift require a comprehensive exposure evaluation. With the exception of routine "assembly line" operations, where sound level meters can be used to characterize exposures, most processes are best evaluated using dosimeters. Also, an octave band analysis can be useful in determining the source and frequency of the noise so that appropriate sound-absorptive materials or a barrier for controlling the path of the sound can be selected. The NIOSH criteria document on noise [NIOSH 1972b] discusses equipment and procedures for monitoring noise levels, along with recommendations for reducing exposures and implementing a hearing conservation program.

3. Biological Monitoring

Biological indicators may be useful for assessing human exposures to certain contaminants in the welding environment. Further information may be found in Section B,2 of this chapter (Biological Monitoring).

B. Medical Monitoring

Workers exposed to chemical and physical agents associated with welding processes are at risk of suffering adverse health effects. The respiratory system, eyes, and skin require particular attention during medical examinations conducted for preplacement, periodic monitoring, emergencies, or employment termination.

Medical monitoring as described below should be made available to all workers. The employer should provide the following information to the physician responsible for the medical monitoring program:

- Any specific requirements of the applicable OSHA standard or NIOSH recommended standard
- Identification of and extent of exposure to physical and chemical agents that may be encountered by the worker
- Any available workplace sampling results that characterize exposures for job categories previously and currently held by the worker
- A description of any protective devices or equipment the worker may be required to use
- The composition and toxic properties of the materials used in welding
- The frequency and nature of any reported illness or injury of a worker

1. Medical Examinations

The objectives of a medical monitoring program are to augment the primary preventive measures, which include industrial hygiene monitoring of the workplace, the implementation of engineering controls, and the use of proper work practices and personal protective equipment. Medical monitoring data may also be used for epidemiologic analysis within large plants and on an industry-wide basis; they should be compared with exposure data from industrial hygiene monitoring.

The preplacement medical examination allows the physician to assess the applicant's functional capacity and, insofar as possible, to match these capabilities with the physical demands and risks of the job. Furthermore, it provides baseline medical data that can be compared with any subsequent health changes. This preplacement examination should also provide information on prior occupational exposures.

The following factors should be considered at the time of the preplacement medical evaluation and during ongoing medical monitoring of the worker: (a) exposure to chemical and physical agents that may exert independent and/or interactive adverse effects on the worker's health (including exacerbation of certain preexisting health problems and synergism with nonoccupational risk factors such as cigarette smoking), (b) ancillary activities involved in welding (e.g., climbing and lifting), and (c) potentially hazardous characteristics of the worksite (e.g., confined spaces, heat, and proximity to hazards such as explosive atmospheres, toxic chemicals, and noise). The specific types of information that should be gathered are discussed in the following subsections.

a. Preplacement Examination

(1) Medical History

The medical history should include information on work, social activities, family, and tobacco-smoking habits [Guidotti et al. 1983]. Special attention should be given to any history of previous occupational exposure to chemical and physical agents that may be potentially hazardous.

(2) Clinical Examination

The preplacement examination should ascertain the worker's general fitness to engage in strenuous, hot work. Welding processes entail the use of equipment that is often heavy and that may generate potentially harmful levels of UV radiation, heat, noise, fumes, and gases. The preplacement examination should be directed toward determining the fitness of the worker to perform the intended job assignment.

Appropriate pulmonary and musculoskeletal evaluation should be given to workers whose jobs may require extremes of physical exertion or stamina (e.g., heavy lifting), especially those who must wear personal respiratory protection. Because the standard 12-lead electrocardiogram is of little practical value in monitoring for nonsymptomatic cardiovascular disease, it is not recommended. More valuable diagnostic information is provided by physician interviews of workers that elicit reports of the occurrence and work-relatedness of angina, breathlessness, and other symptoms of chest illnesses. Special attention should also be given to workers who require the use of eye glasses; to assure that these workers must be able to wear simultaneously any equipment needed for respiratory protection, eye protection, and visual acuity, and they must be able to maintain their concurrent use during work activities.

Specific welding processes entail potential exposure to diverse chemical agents known to cause specific occupationally related adverse health effects. These are known as sentinel health events (occupational), or SHE(O)s [Rutstein et al. 1983]. For example, heating of metals with low-boiling points (such as zinc and cadmium) may result in metal fume fever. Exposure to cadmium fumes may result in delayed onset of pulmonary edema and may lead to pulmonary fibrosis and cancer. Nickel and chrome are both found in stainless steel and may cause allergic sensitization as a result of an acute exposure or cancer as a result of chronic exposure. Welding processes that involve the use of flux may generate irritating concentrations of fluorides. Welding on painted metal may result in exposure to lead or other chemical agents, and welding on materials cleaned with a chlorinated solvent may cause photodecomposition of the solvent with resulting exposure. In addition, the worker's duties may be performed in proximity to unrelated operations that generate potentially harmful exposures (e.g., asbestos or cleaning or degreasing solvents). The physician must be aware of these potential exposures to evaluate possible hazards to the individual worker.

(3) Special Examinations and Laboratory Tests

A pulmonary function test (PFT) and a 14- by 17-in. (36- by 43-cm) postero-anterior chest radiograph should be taken and kept as part of the worker's medical record [American Thoracic Society 1982]. The preplacement chest radiograph and PFT gives the physician objective information with which to assess a worker's fitness for a specific job; it may also prevent confusion or misinterpretation of any subsequent lung tissue changes.

The International Labour Office (ILO) stresses the importance of radiographic technique in the detection of early pneumoconiosis. High-speed and miniature films are not recommended. Films should be interpreted using the current recommendations of the ILO [ILO 1980]. Classification of films should be made by NIOSH-certified B readers [Martin 1985]. Although the short classification may be useful for clinical purposes, films that are obtained in a workplace program of medical monitoring for respiratory hazards must be read and recorded by the complete classification [Martin 1985].

Preplacement audiograms of all workers are recommended, since welders, brazers, and thermal cutters may be exposed to noise intensities exceeding prescribed levels.

b. Periodic Medical Examination

A periodic medical examination should be conducted at least annually or more frequently, depending on age, health status at the time of a prior examination, and reported signs or symptoms associated with exposure to welding emissions. The purpose of these examinations is to detect any work-related changes in health at an early stage. The physician should note any trends in health changes revealed by epidemiologic analyses of examination results. The occurrence of an occupationally related disease or other work-related adverse health effects should prompt an immediate evaluation of industrial hygiene control measures and an assessment of the workplace to determine the presence of a previously unrecognized or potential hazard.

The physician's interview with the worker is an essential part of a periodic medical examination. The interview gives the physician the opportunity to learn of changes in (a) the type of welding performed by the worker, (b) metals and/or fluxes being used, (c) the work setting (e.g., confined spaces), and (d) potentially hazardous workplace exposures that are in the vicinity of the worker but are not attributable to the worker's on-the-job activities.

Because radiographic abnormalities may appear before pulmonary impairment is clinically manifested or otherwise detectable, periodic chest radiographs are routinely recommended for monitoring workers exposed to fibrogenic respiratory hazards [American Thoracic Society 1982]. However, the chest radiograph may not distinguish between a relatively benign disease such as siderosis (caused by iron oxide exposure) and a disease that may be of greater medical importance such as pneumoconiosis.

Under ordinary conditions, chest radiographs may be obtained for workers at 1- to 5-year intervals, depending on the nature and intensity of specific exposures and related health risks. Workers with 10 years or more of exposure and workers previously employed in dusty jobs may require chest radiographs at more frequent intervals. These intervals may be changed as called for by other regulatory requirements or at the discretion of the examining physician. For example, a previous radiograph (e.g., one taken at the time of hospitalization) may be substituted for one of the periodic chest radiographs if it is made available and is of acceptable quality. If a worker has radiographic evidence of pneumoconiosis or spirometric/symptomatic evidence of pulmonary impairment, the physician should counsel the worker and employer about the potential risks of further exposure and the benefits of removing the worker from exposure. Smokers should be counseled about how smoking may enhance the adverse effects of other respiratory hazards.

Epidemiologic studies suggest an association between exposure to airborne welding fumes and gases and an excessive risk of lung cancer. Because routine chest radiographs and sputum cytology are inadequate for detecting bronchogenic carcinoma early enough to alter the course of the disease, they are not currently recommended as part of regular medical monitoring for lung cancer in workers.

During the periodic medical examination of individual welders, the physician should reexamine the skin, eyes, and other organ systems at risk to note changes from the previous examination. The physician should direct special attention to evidence of burns and effects from exposure to UV radiation and solvents. This evidence may suggest inadequate industrial hygiene control measures, improper work practices, or malfunctioning equipment (e.g., exposure to metal spatter, flying sparks, UV light flashes, or degreaser solvents). In addition, the physician should be vigilant for musculoskeletal morbidity attributable to ergonomic problems caused by inadequate worker training on the handling of equipment or by improper working position (e.g., kneeling and overhead welding).

When welders are exposed to agents for which there is an existing OSHA standard or for which NIOSH has recommended medical monitoring, physicians should refer to the appropriate standard or recommendation for guidance on specific medical examinations. Appendix B lists published sources of NIOSH RELs for hazardous agents associated with various welding operations.

Hazardous agents that are commonly associated with welding processes are listed in Table VI-3 along with their potential toxic effects and recommendations for additional tests.

2. Biological Monitoring

Urinary or blood concentrations of lead, cadmium, chromium, and aluminum, and urinary concentrations of fluoride ions may be useful biological indicators of worker exposure to welding emissions. Several studies have correlated exposures to welding fumes containing chromium [Tola et al. 1977; Mutti et al. 1979; Kalliomaki et al. 1981; Sjogren et al. 1983a], aluminum [Sjogren 1983b; Mussi et al. 1984], or fluoride [Krechniak 1969; Pantucek 1975] with their urinary or blood concentrations. However, biological monitoring may not be sensitive enough to use as a primary monitoring measure. For example, Tola et al. [1977] found no increase in urinary chromium concentrations when environmental chromium concentrations were within the NIOSH REL. Biological monitoring has the potential for assessing total exposure when the work load (physical activity) and the routes of exposure are taken into account. Mutti et al. [1979] and Pantucek [1975] showed that urinary levels of chromium and fluoride can provide information on either current exposure or body burden, depending on the timing of the sample collection. Schaller and Valentin [1984] concluded that aluminum concentration in serum seemed to be an indicator of body burden, and that aluminum concentration in urine seemed to be an indicator of current exposure. Thus biological monitoring may be a useful adjunct for detecting accidental exposure or a failure of primary control measures.

Table VI-3.—Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
<u>Gases</u>:			
Acetylene[c]	Anesthesia (at high concentration)	N/A	
Carbon monoxide	Headache, nausea, dizziness, collapse, death	Cardiovascular effects (cardiomyopathy, exacerbates existing coronary artery disease)	Carboxyhemoglobin (COHb)
Oxides of nitrogen	Pneumonitis, pulmonary edema	Chronic bronchitis, emphysema, pulmonary fibrosis	
Ozone	Respiratory tract irritation (cough, chest tightness), dryness of mucous membranes, headache, sleepiness, fatigue, pulmonary edema, wheezing	Pulmonary insufficiency	
Phosgene	Pneumonitis, pulmonary edema	Emphysema, pulmonary fibrosis	
<u>Metals</u>:			
Arsenic	Dermatitis, gastrointestinal symptoms (nausea, vomiting, diarrhea)	Cancer (lung, lymphatic, skin), skin (hyperpigmentation, palmar/plantar warts, hyperkeratosis), anemia, leukopenia, cardiomyopathy, hepatic cirrhosis, peripheral neuritis (numbness, weakness, ataxia)	
Beryllium	Skin (ulcers, dermatitis); conjunctivitis; rhinitis, pharyngitis, tracheobronchitis, chemical pneumonitis	Cancer (lung), pulmonary symptoms (cough, chest pain, cyanosis), systemic weakness, enlargement of liver and spleen	

(continued)

See footnotes at end of table.

Table VI-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Cadmium	Pulmonary edema (cough, dyspnea, chest tightness), nasal irritation & ulceration	Cancer (prostate, lung); pulmonary fibrosis, emphysema, honeycomb lung; kidney (proteinuria-low molecular); hematopoietic disturbance (anemia); skeletal (suspected osteomalacia); prostate examination (for workers 40 years and older); anosmia (loss of sense of smell)	Blood urea nitrogen (BUN), complete blood count (CBC), low MW protein in urine
Chromium(VI)[d]	Skin irritation (dermatitis, ulcer), respiratory tract irritation, and effects on nose (epistaxis, septal perforation), eyes (conjunctivitis), and ears (tympanic membrane perforation)	Cancer (lung), kidney and liver damage (suspected)	
Cobalt	Pulmonary sensitization (asthma-like reaction), skin sensitization and irritation	Pulmonary fibrosis, thyroid hyperplasia (possible), polycythemia (possible)	
Copper	Metal fume fever,[e] nasal mucosa irritation	Not known	
Iron		Siderosis (pulmonary deposition of iron dust)	
Lead		Nervous system (neuropathy-extensor palsy), gastrointestinal symptoms (anorexia, constipation, abdominal colic), nephropathy, reproductive effects (on fetal brain), hematopoietic effects (porphyrin metabolism disturbance)	Zinc protoporphyrin (ZPP)

(continued)

See footnotes at end of table.

Table VI-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Magnesium	Irritation of nasal mucosa and conjunctiva, metal fume fever[e]	Not known	
Manganese	Chemical pneumonitis	Nervous system (irritability, drowsiness, impotence, muscular rigidity, spasmodic laughing/ weeping, speech & gait disturbances)	
Molybdenum	Irritation of mucous membranes (eyes and nose)		
Nickel	Dermatitis, asthma-like lung disease	Cancer (nose, larynx, and lung), upper and lower respiratory tract irritation (nose bleeding, ulcer and septal perforation), renal dysfunction	
Silver		Argyria or argyrosis (pigmentation of skin and eyes resulting from silver deposition)	
Tin		Stannosis (pneumoconiosis resulting from inhalation of tin oxide)	
Titanium		Pneumoconiosis	
Tungsten[f]	Conjunctivitis, upper respiratory tract irritation (cough, dyspnea)	Extrinsic asthma, pneumoconiosis, diffuse interstitial pneumonitis, fibrosis	
Vanadium	Upper and lower respiratory tract irritation (nose bleeding, cough), conjunctivitis, dermatitis	Chronic bronchitis, emphysema, pneumonia, chronic eye irritation, dermatitis, possible skin and/or respiratory allergy	

(continued)

See footnotes at end of table.

Table VI-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Zinc	Metal fume fever[e], skin eruption (oxide pox)	Not known	
Other minerals:			
Asbestos		Cancer (lung, mesothelium), asbestosis, pleural thickening	
Fluorides	Respiratory irritation, gastro-intestinal symptoms	Osteosclerosis, pulmonary insufficiency, kidney dysfunctions[g]	Post-shift urinalysis for F; bone density on periodic chest X-ray; renal functions[g]
Silica		Silicosis	
Physical agents:			
Electricity	Electrocution, burns	Not known	
Hot environments	Heat rash, heat cramps, heat exhaustion (irritability, mental dullness, general weakness), heat stroke	Not known	
Noise	Temporary auditory threshold shift	Hearing loss	
Vibration		Vibration white finger syndrome, Raynaud's phenomenon resulting from localized vibration (tingling numbness, blanching of fingers)	

(continued)

See footnotes at end of table.

Table VI-3 (Continued).--Hazardous agents associated with welding processes and their potential toxic effects

Hazardous agent	Toxic effects[a]		Supplemental tests[b]
	Short-term	Long-term	
Ionizing radiation	Erythema, radiodermatitis, nausea, vomiting, diarrhea, weakness, bone marrow depression, shock, death	Cancer, cataracts, reproductive effects	Film badges or dosimeters
Ultraviolet radiation (200-400 nm)	Photokeratitis, conjunctivitis, skin erythema and burns	Cancer (skin), cataracts	
Visible light (400-760 nm)	Eye discomfort, fatigue, headache, retinal changes (retinal burn)	Eye discomfort, fatigue, headache, retinal changes (retinal burn)	

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[a] Distinction between short-term and long-term effects is not clear-cut and is somewhat arbitrary. Short-term effects are usually the result of acute exposure(s) and may appear immediately to several days or weeks after the exposure. Long-term effects are usually the result of chronic, repeated low-dose exposures extending from several months to many years. However, long-term effects may also include the aftereffects of single or repeated acute exposures.

[b] Tests to be considered at the discretion of the attending physician.

[c] May contain toxic impurities such as arsine, carbon disulfide, carbon monoxide, hydrogen sulfide, and phosphine.

[d] Toxicity information is mostly from chromium plating operation and chromium pigment manufacturing.

[e] Metal fume fever is manifested by fever, chills, cough, joint and muscle pains, and general malaise.

[f] Reports of health effects of tungsten come almost exclusively from the studies of workers exposed to tungsten carbide, which usually contains cobalt.

[g] Renal functions should be evaluated because renal dysfunctions are known to hinder urinary excretion of fluorides.

3. Recordkeeping

Medical records and exposure monitoring results must be maintained for workers as specified in Chapter I, Section 10(c) of this document. Such records must be kept for at least 30 years after termination of employment. Copies of environmental exposure records for each worker must be included with the medical records. These records must be made available to the worker or former worker or to anyone having the specific written consent of the worker, as specified in Chapter I, Section 10(d) of this document.

4. Ergonomic Monitoring

Ergonomic factors in the workplace should be assessed to determine the need for changes in the work environment, equipment, or work practices, or compensating exercises to avoid fatigue or injury. Work postures, vibrating equipment, and moving of heavy objects may all strain the muscles and joints of welders. The static positions frequently used in welding and similar processes may also create ergonomic problems that require analysis. For example, several studies [Herberts and Kadefors 1976; Kadefors et al. 1976; Petersen et al. 1977] have indicated that overhead welding may severely strain the supraspinatus muscle of the shoulder, leading to tendinitis. The movement of workpieces and distribution of workloads may also require study and planning.

Ilner-Paine [1977] reported the use of video monitoring to observe and record the physical exertion of welders while they worked. This technique was useful in diagnosing the causes of back and shoulder pain among shipyard welders. Grandjean [1981] has published additional information on ergonomic principles that can be adapted to jobs typically performed by welders.