Several of the studies that explored the relationship between exposure to welding fumes and gases and the incidence of mortality from lung cancer among welders, suffered from one or more of the following methodologic problems: (1) incomplete information on the extent of exposure, requiring estimations of these exposures from job titles, (2) insufficient cohort size and person years to observe elevated risks of lung cancer, and (3) confounding variables such as smoking and exposure to asbestos. These limitations make it difficult to draw definitive conclusions about the cause of cancer excesses observed within each study. However, collectively these studies demonstrate an elevated risk of lung cancer among welders that is not completely accounted for by smoking or asbestos exposure, and that appears to increase with the latent period from onset of first exposure and duration of employment. Additionally, a few of the studies suggest a strong association between lung cancer risk and exposures generated while welding on stainless steel. This association could be attributed to the carcinogenic properties of the nickel and chromium found in the fume.

An overview of each evaluated study is presented in Tables IV-2 through IV-4.

b. Kidney and Other Urinary Tract Cancers

The cohort mortality studies conducted by Puntoni et al. [1979], Milham [1983], and Becker et al. [1985] have shown a statistically significant increased risk of kidney or other urinary tract cancers in welders. The study by Puntoni et al. [1979] of shipyard workers showed ORs of 5.06 ($p<0.05$) and 5.88 ($p<0.05$) for cancer of the kidney and other urinary organs in gas welders when compared to the male population of Genoa, Italy and the male staff at St. Martino Hospital, respectively. Although the ORs were elevated for these cancers in electric welders, they were not statistically significant. When all shipyard workers were grouped and compared with either comparison population, the elevated ORs for these cancers were found to be statistically significant ($p<0.0005$).

Similarly, the study reported by Milham [1983] showed statistically significant ($p<0.01$) increased PMRs for kidney cancer in male welders and flamecutters who had been employed in Washington State. Welders and flamecutters analyzed during the period 1970-1979 and for the total observation period 1950-1979 had PMRs of 234 and 182, respectively.

The observations of Becker et al. [1985] were consistent with these findings with an OR of 15.0 (3 observed versus 0.2 expected) for kidney and other urinary tract cancers in welders when compared with the German national death rates. Although it was not reported by the authors, NIOSH calculated a p value of 0.002 (95% CI=3.09-43.83).

As described earlier in this Chapter in Section B,2,a(2)(a), these three studies had a number of methodologic problems, including a lack of information on potential occupational exposures. Because of these limitations, the possible etiology for these observed cancers is difficult to assess.

c. Reproductive Effects

Adverse reproductive effects (e.g., infertility or spontaneous abortions) have been reported by Rachootin and Olsen [1983] and Lindbohm et al. [1984] for both men and women who were either employed as welders or who were potentially exposed to metals. A case-control study was conducted by Rachootin and Olsen [1983] to determine whether an association existed between delayed conception or infertility and the occupations of women and their husbands. The study population was identified from the inpatient register at a large Danish hospital; 1,069 case couples and 4,305 comparison couples were identified as study candidates. Case couples were undergoing evaluation for fertility problems, and the female partner had been admitted to the hospital for testing during the period 1977 to 1980. Comparison couples had had a healthy child born at the same hospital during the period 1977 to 1979. A questionnaire was mailed, and responses were received from 87% of each group (927 case and 3,728 comparison couples). All information on a couple was solicited from the woman. Three types of analyses were conducted.

The first analysis compared the reported occupational exposures of the case and comparison couples residing in the hospital's direct catchment area (Table IV-6). In this analysis, comparison couples were limited to those of the 3,728 comparison couples who were the parents of a healthy child conceived within 1 year. The case couples were restricted to those of the 927 case couples who were examined or treated for infertility of at least 1 year's duration. This analysis examined three subgroups of case couples: (1) those with a male partner having abnormal sperm number, motility, or shape, (2) those with a female partner having hormonal disturbances, and (3) those with idiopathic infertility. The first two subgroups had medical histories that were potentially related to occupational exposures.

The second analysis compared the reported occupational exposures of case couples (Table IV-7). The three subgroups from the first analysis were compared with infertile case couples having conditions that were unlikely to be caused directly by occupational exposures (e.g., varicocele or history of mumps as an adult in the male, or blocked fallopian tubes or endometriosis in the female).

The third analysis compared two subgroups within the original comparison group of couples who had had a healthy child born at the study hospital during the period 1977 to 1979. One subgroup was made up of comparison couples who had given birth to a healthy child after a conception delay of more than 1 year, and the second

Table IV-6.—Odds ratios and 95% confidence intervals for three subgroups of case couples compared with comparison couples, by reported occupational exposures[a]

Type of exposure	Men with sperm abnormalities OR[b]	Men with sperm abnormalities 95% CI[c]	Women with hormone imbalance OR	Women with hormone imbalance 95% CI	Couples with idiopathic infertility: Women OR	Couples with idiopathic infertility: Women 95% CI	Couples with idiopathic infertility: Men OR	Couples with idiopathic infertility: Men 95% CI
Lead, mercury, cadmium:								
Uncorrected data	0.9	0.5-1.6	0.3	0.1-1.3	2.9	1.4-6.3	0.8	0.3-1.8
Corrected data[d]	—	—	—	—	2.6	1.1-5.9	—	—
Welding of stainless steel:								
Uncorrected data	1.7	1.0-2.8	—	—	—	—	1.2	0.5-2.8
Corrected data[d]	1.7	0.9-2.9	—	—	—	—	—	—
Welding of other metals	1.0	0.7-1.4	1.2	0.3-5.0	—	—	1.4	0.9-2.3
Heat:								
Uncorrected data	1.8	1.2-2.6	1.2	0.6-2.5	1.8	0.8-4.3	1.6	0.9-2.7
Corrected data[d]	19.9	1.2-2.8	—	—	—	—	1.6	0.9-2.8
Noise:								
Uncorrected data	1.3	0.9-1.8	2.2	1.5-3.1	2.4	1.4-4.0	1.3	0.8-2.0
Corrected data[d]	1.3	0.9-1.9	2.1	1.4-3.2	2.2	1.3-3.9	—	—

[a]Adapted from Rachootin and Olsen [1983].
[b]Odds ratio.
[c]Confidence interval.
[d]Corrected for female partner's age, education, residence, and parity.

Table IV-7.—Odds ratios and confidence intervals for three subgroups of case couples compared with all other case couples, by reported occupational exposures[a,b]

	Men with sperm abnormalities		Women with hormone imbalance		Couples with idiopathic infertility			
					Female Partner		Male Partner	
Type of exposure	OR[c]	95% CI[d]	OR	95% CI	OR	95% CI	OR	95% CI
Lead, mercury, cadmium	0.9	0.5–1.8	0.4	0.1–1.4	1.9	0.7–5.2	0.7	0.3–1.7
Welding of stainless steel	1.1	0.6–2.1	0.8	0.1–13.5	—	—	0.6	0.2–1.5
Welding of other metals	0.8	0.5–1.3	1.1	0.3–5.1	0.7	0.1–2.1	1.0	0.6–1.6
Heat	1.3	0.8–2.1	0.6	0.3–1.2	0.9	0.4–2.1	0.9	0.5–1.7
Noise	1.1	0.7–1.6	0.7	0.5–1.1	0.8	0.5–1.5	0.8	0.5–1.3

[a]Adapted from Rachootin and Olsen [1983].
[b]All other case couples were those whose infertile conditions were unlikely to be related directly to occupational exposures (e.g., varicocele or mumps in the adult male or blocked fallopian tubes in the female.
[c]Odds ratio.
[d]Confidence interval.

subgroup comprised the remaining comparison couples who had conceived a healthy child within 1 year.

A variety of potentially important occupational exposures were considered in the analysis, and those relevant to the welding environment are shown in Tables IV-6, IV-7, and IV-8. In both the first analysis (Table IV-6) and the third analysis (Table IV-8), significantly elevated ORs were seen for a variety of occupational exposures associated with welding. Exposure to heat and noise was consistently associated with elevated ORs. Exposure to heavy metals and welding (either on stainless steel or other metals) was also associated with elevated ORs. Both men and women who were assigned to the exposure category "Welding of Other Metals" in the third analysis (Table IV-8) had a statistically significant increase ($p<0.05$) in delayed conception, with ORs of 1.4 (95% CI=1.1-1.8) for men and 2.4 (95% CI=1.1-5.1) for women. This risk was still statistically significant for women after adjustment for age and education, parity, area of residence, smoking habits, alcohol consumption, and past use of oral contraceptives. In contrast, men and women who were assigned to the exposure category "Welding of Stainless Steel" had no statistically significant increase in delayed conception. In the second analysis (Table IV-7), none of the exposures potentially encountered in the welding environment were associated with elevated ORs.

Lindbohm et al. [1984] evaluated possible influences of paternal or maternal occupations and exposures on spontaneous abortion by linking discharge records from Finnish hospitals with national census data. For the period 1973 to 1976, data were available for 294,309 pregnancies. Census data on occupations were used to form seven categories of presumed exposure to specific agents (animal microorganisms, solvents, polycyclic aromatic hydrocarbons, automobile exhaust fumes, other chemicals, metals, textile dust). Because the census data referred to occupations in 1975, the analysis of spontaneous abortion was limited to pregnancies in 1976. Women in these exposure categories were compared with all other "economically active" women, and wives of exposed men were compared with wives of nonexposed men. A logistic regression model was used to control for age, place of residence, parity, marital status, and age-parity interaction. None of the specific exposures were associated with a significantly increased odds ratio. The odds ratio was 0.78 (95% CI=0.54-1.13) for women exposed to metals (iron and metalware workers; smelting, metallurgic, and foundry workers; miners and quarry workers). For the wives of similarly exposed men, the OR was significantly reduced to 0.86 (95% CI=0.75-0.95).

Lindbohm et al. [1984] also used the pregnancy data for the period 1973 to 1976 to investigate spontaneous abortion by occupation. Women in five occupations had elevated ORs, but none appeared to be related to the welding environment. One of four occupations associated with increased ORs for the wives of exposed men was "metal-plate and constructional steel workers" with an OR of 1.36 (95% CI=1.00-1.85). This occupational category was not

Table IV-8.--Odds ratios and 95% confidence intervals for comparison couples who had delayed conception compared with comparison couples who conceived within 1 year, by reported occupational exposures[a]

Type of exposure	Men		Women	
	OR[b]	95% CI[c]	OR	95% CI
Lead, mercury, cadmium:				
Uncorrected data	1.3	0.9-1.8	1.7	1.1-2.8
Corrected data[d]	1.3	0.9-1.8	1.7	1.0-2.8
Welding on stainless steel	1.0	0.6-1.6	1.1	0.1-8.8
Welding of other metals:				
Uncorrected data	1.4	1.1-1.8	2.4	1.1-5.1
Corrected data	1.3	1.0-1.7	2.7	1.2-6.3
Heat:				
Uncorrected data	1.8	1.4-2.4	1.5	1.0-2.4
Corrected data	1.9	1.5-2.6	1.4	0.9-2.3
Noise:				
Uncorrected data	1.3	1.0-1.6	1.7	1.3-2.3
Corrected data	1.3	1.0-1.6	1.9	1.4-2.6

[a]Adapted from Rachootin and Olsen [1983].
[b]Odds ratio.
[c]Confidence interval.
[d]Corrected for female partner's age, education, residence, parity, smoking and drinking habits, and past use of oral contraceptives.

described in any further detail except for the comment that these men "are occasionally exposed to chromates and nickel." No information was available on smoking habits and alcohol consumption. Potential occupational exposures were assigned based on employment history.

The significance of the results from these two studies [Rachootin and Olsen 1983; Lindbohm et al. 1984] is questionable given the studies' limitations (e.g., estimation of exposures and confounding exposures of smoking or alcohol consumption).

d. Cardiovascular Effects

A few case reports indicated that exposure to welding fumes and gases may cause acute cardiac episodes or aggravate preexisting cardiovascular diseases in welders [Beintker 1932; Jacobi 1934]. In these case reports, welders worked in confined spaces with poor ventilation. No information was given as to the types of metal being welded or exposures being generated.

Two of four mortality studies cited previously in this Chapter in Section B,2,a,(2),(a) reported increased risks of cardiovascular disease in welders employed at shipyards [Puntoni et al. 1979; Newhouse et al. 1985]. Newhouse et al. [1985] observed an increased SMR of 130 (90% CI=104-156) for ischemic heart disease in welders, whereas Puntoni et al. [1979] reported ORs greater than 1.00 for a similar cohort of welders. Neither study was adjusted for smoking and no conclusions were drawn by the authors as to the relevance of the elevated risks. One of the other two mortality studies [Milham 1983] reported a PMR of 97 for welders and flame cutters when analyzed for the total study period of 1950-79; the other study [Polednak 1981] showed SMRs of 70 and 82 for welders exposed and nonexposed to nickel oxide fumes, respectively. The slightly higher SMR of the nonexposed group of welders could be attributed to the 2.5 times greater percentage of cigarette smokers reported among this group.

e. Gastrointestinal Effects

Gastrointestinal disorders in welders experiencing metal fume fever usually take the form of nausea, vomiting, and gastrointestinal cramps [Rohrs 1957; Papp 1968]. These effects appear to subside within 24 to 48 hr after acute exposure to welding fumes.

Two cases of gastrointestinal disorders were reported by Rieke [1969] in workers performing oxyacetylene torch cutting of scrap metal. Both men had been employed in a ferrous metal scrap yard where they disassembled and cut large (often painted) metal parts. The men complained of back and lower abdominal pains, poor appetite, and constipation after being exposed for several days to metal fumes. Urinary lead analysis revealed markedly elevated lead levels (e.g., 0.44 and 0.43 mg lead/liter) and both men were treated for lead intoxication and given calcium disodium edetate for several days. Following this period of treatment all gastrointestinal disorders ceased. The workers' health problems were attributed to exposure to lead contained in the paints.

In three epidemiologic studies [Mignolet 1950; Stancari and Amorati 1963; Rozera et al. 1966], an increased incidence of digestive disorders in welders was reported. Rozera et al. [1966] reported that 22% of a population of 620 welders had digestive system disorders compared with 12% found in the general industrial population. Mignolet [1950] reported similar finding among 216 welders who were placed into three groups according to the welding process they used. Thirty-five out of 85 (41%) shielded metal arc welders complained of digestive disorders, including loss of appetite, slow digestion, and nausea. Two out of 99 (2%) oxyfuel gas welders had gastric ulcers. Two out of 32 (6.3%) oxyacetylene cutters had symptoms of gastrointestinal disorders. These disorders were attributed to the inhalation of fumes from certain types (unspecified) of covered electrodes because no similar effects were noted in welders who used bare metal electrodes. Most of the symptoms associated with digestive disorders disappeared during weekends and vacations.

Gastroduodenopathies were reported by Stancari and Amorati [1963] in 264 arc welders aged 17 to 58 years. Of the 264 arc welders, 67% of those with over 10 years work experience, 43% of those with 3 to 10 years work experience, and 15% of those with less than 2 years experience had gastritis, gastroduodenitis, or gastroduodenal ulcer. The authors concluded that the inhalation of fumes and gases associated with arc welding caused the gradual development of chronic gastritis and gastroduodenitis among welders. These ulcers were described as moderate and responded well to treatment; as soon as welding was discontinued, regression occurred. The authors further stated that the specific cause of these ulcers was unknown.

Houten and Bross [1971] reported on the relative risk of cancer among male patients at a regional cancer institute. Cancer patients were compared with other admitted male patients who did not have neoplastic disease in an attempt to ascertain if specific types of cancers were associated with certain occupations. Three cases of stomach cancer were noted among welders and flamecutters, for an OR of 2.5. This cancer incidence was not statistically significant due to the small number of observed cases. In contrast, several of the mortality studies [Milham 1983; Puntoni et al. 1979; Polednak 1981; Becker et al. 1985] discussed previously in this Chapter in Section B,2,a,(2),(a) reported no increases in welder mortality as a result of cancer or other diseases of the digestive system.

f. Ophthalmologic Effects

Persons who are involved in or working near welding processes are at risk of eye injury from metal spatter and exposure to nonionizing electromagnetic radiation in the UV to IR wavelengths [NIOSH 1972a; Marshall et al. 1977]. Exposure to UV radiation from the welding arc can result in acute keratoconjunctivitis, also known as arc eye, welder's flash, or actinic ray photokeratitis. This inflammatory disorder affects the outer structure of the eye (cornea, conjunctiva, iris) and causes blurred vision, lacrimation, burning pain, and headache [NIOSH 1972a; Palmer 1983]. These symptoms usually appear within 4 to 12 hr after the beginning of the exposure and last up to 2 days. The visible radiation emitted during welding can penetrate the eye and be absorbed by the retina and choroid causing retinal injury [Palmer 1983; Marshall et al. 1977]. Similarly, exposure to the IR radiation wavelength can cause thermal damage to the cornea and aqueous humor of the eye and has been associated with the formation of lenticular cataracts [Palmer 1983].

These types of adverse ocular effects have been reported in welders who were wearing improper eye protection or no protection at all [Minton 1949; Sykowski 1951; Entwistle 1964; Karai et al. 1984]. In one study [Entwistle 1964], 31 eye injuries were reported that were caused by contact with hot slag, metal chips, sparks, and hot electrodes. Several of the injuries involved workers assisting welders, and others involved welders who had been provided with approved types of faceshields but did not use them properly. Golychev and Nikatina [1974] also reported that because eye protection was not used, cataracts occurred in a 42-year-old welder's helper who had regularly assisted electric arc welders for 19 years. This worker reportedly suffered from welder's flash and conjunctivitis 3 to 4 times a month. Other studies [Minton 1949; Sykowski 1951] have reported similar cases of retinitis and dendritic keratitis in welders who did not protect their eyes while igniting their arcs. In a case control study of 118 welders, a statistically significant ($p<0.05$) increase was observed in damage to the corneal epithelium and endothelium of the eye when compared to 85 nonwelders [Karai et al. 1984]. The increase in eye injuries was attributed to exposure to ultraviolet radiation.

Two studies [Mignolet 1950; Gupta and Singh 1968] have reported on the evaluation of visual acuity of welders. The visual acuity was evaluated in a group of 520 welders, of whom approximately 76% were under 40 years of age; 23% of the study group worked for 20 years and 20% worked up to 30 years [Gupta and Singh 1968]. Eye complaints that included watering, blurred vision, burning, soreness, and haziness were reported by 60% of the welders. The principal clinical conditions, reported in descending order of frequency, were conjunctivitis (45%), keratoconjunctivitis (11%), pterygium (7%), incipient cataract (7%), edema of the lids (5%), brown pigmentation around the cornea (4%), trachoma (2%), corneal opacity (2%), and dilated pupils (2%). The two most common eye injuries were imbedded foreign bodies in the eye (21%) and burns of the conjunctiva (4%). Almost all the welders had suffered from arc flash at least once. Visual acuity in 33% of the welders was at the minimum accepted acuity for welders (20/30). Serious visual impairment was observed in 20%; substandard acuity of 20/60 or less was present in 59% of the welders; and defective muscle balance of the eyes was noted in 78%. The percentage of welders with defective visual performance increased with age. A similar investigation of visual acuity was made in a group of 216 welders [Mignolet 1950]. Although the types of tests conducted were not stated, unilateral and bilateral alterations in visual acuity were reported for 41% of the oxyfuel gas welders, 47% of the oxyacetylene cutters, and 58% of the arc welders. Two cases of cataracts were also noted. No control groups were used in either study for comparison of visual acuity.

g. Dermatologic Effects

Dermal effects related to welding processes may result from exposure to UV radiation [Grimm and Kusnetz 1962; Pattee et al. 1973; Balabanow et al. 1967; Roquet-Doffiny et al. 1977; Ross 1978] and IR radiation [Lydahl 1984; Moss et al. 1985], from hot metal spatter [Britton and Walsh 1940; Entwistle 1964; CDLSR 1975], and from sensitization to metals [Kaplan and Zeligman 1963; Fregert and Ovrum 1963; Shelley 1964; Kalliomaki et al. 1977].

Exposure of the welder's skin to UV radiation can result in skin burns similar to sunburn. According to a review by Pattee et al. [1973], the most common sites for such burns are the arms, hands, neck, and chin. Ross [1978] also noted that the front and sides of the neck were the most common sites for such burns. In a clinical investigation conducted by Dreesen et al. [1947], 25% of 3,255 arc welders had burns or scars from burns on their bodies. Similar findings were noted by Entwistle [1964] who reported that over 50 cases of burned fingers, wrists, hands, elbows, arms, and legs occurred among welders during an 8-month period. The cause of those burns was attributed to metal spatter, hot slag, and the flame from oxyacetylene torches. Several case reports have documented the occurrence of chronic dermatitis among welders and other persons working near welding processes [Shelley 1964; Balabanow et al. 1967; Roquet-Doffiny et al. 1977]. Balabanow et al. [1967] reported a case of dermatitis in a welder who had been in this occupation for 35 years. He suffered from edema of the eyelids and redness of the face and neck, the scalp, upper chest, back of hands, forearms, and the lower extremities. A series of clinical tests revealed no pathologic cause for these effects other than welding. A similar finding was reported by Shelley [1964] for a 40-year-old crane operator who worked near welding operations and had had recurrent eczematous eruptions on both hands for 14 years. Roquet-Doffiny et al. [1977] reported a severe case of chronic actinic dermatitis, erythema, atrophic plaques, telangiectasis, and pruritic keratotic lesions for a welder who had been performing oxyacetylene gas welding for 30 years. In addition, over a 4-year period, eight tumors were removed from his face and neck--five basal cell carcinomas and three squamous cell carcinomas. Exposure to radiation and welding fumes and gases was reported in all three reports as the causative factor in the observed skin diseases. When workers discontinued welding or were removed from the work environment where welding was being performed, dermatitis ceased.

Among welders, a number of cases involving chromium skin sensitization have been reported [Fregert and Ovrum 1963; Kalliomaki et al.1977]. Kalliomaki et al. [1977] reported a case of chromium sensitivity involving dermal allergy and asthma for a welder who typically welded on stainless steel. After the individual welded on stainless steel for about 1 hr, bronchial obstruction was observed that, according to the investigator, demonstrated severe sensitivity to the fume exposure. Measurements of airborne hexavalent chromium revealed concentrations of 0.02 to 1.7 mg/m^3. A similar finding was reported by Fregert and Ovrum [1963] for a welder who experienced repeated episodes of facial contact dermatitis while welding. The welder was found to be sensitized to chromium that was emitted while he welded on stainless steel or from the welding rod that contained trace amounts of chromium. The dermatitis disappeared after the welder ceased his exposure to welding fumes that contained chromium.

h. Auditory Effects

Hearing loss among welders has usually been due to traumatic injury [Frenkiel and Alberti 1977] or to excessive sound pressure [Hickish and Challen 1963; Bell 1976]. Frenkiel and Alberti [1977] reviewed 11 cases of middle ear trauma resulting from burns, including 5 such cases in welders. The eardrums of the welders were perforated by flying sparks or pieces of metal during welding processes. In four of the five cases, hearing loss was permanent. Auditory impairment from exposure to excessive noise levels may occur during arc air gouging of metal, and plasma torch processes [Hickish and Challen 1963; Bell 1976]. Bell [1976] reported that a considerable risk of noise-induced deafness was possible among a group of welders during arc air gouging in which sound level measurements exceeded 115 dbA. Hickish and Challen [1963] noted a mean temporary hearing loss in both ears of 19 dB at 4,000 Hz and up to 35 dB at 8,000 Hz in three persons who were exposed to the noise from a plasma torch for 1 hr. In one person, recovery of normal hearing took 48 hr.

i. Musculoskeletal Effects

Welding is a static type of work that usually requires customary postures and considerable shoulder joint motion. Shoulder pain may be caused or aggravated by welding. Complaints of shoulder pain are very common among older welders, according to observations by Herberts and Kadefors [1976], who investigated the clinical and radiological features of shoulder pain in 10 shipyard welders aged 50 to 65 years. An electromyographic (EMG) evaluation of the impact of static loading on their shoulder muscles was also conducted. The most consistent finding was reduced muscle power and shoulder pain. All subjects had normal shoulders upon inspection, but mild local tenderness of the rotator cuff was always present. Measurement of the isometric muscle power revealed reduced power in the painful shoulder in abduction, outward rotation, and flexion. The radiographic appearance was normal in only 3 of the 10 subjects. Analysis of EMG signals recorded during actual overhead welding revealed significant changes in the action potential of the supraspinatus muscle, implying that this muscle is under sustained heavy strain in this working situation.

Kadefors et al. [1976] also studied the effect of overhead welding on muscles of the shoulder in 20 welders aged 20 to 35 years. An inexperienced group consisted of 10 men with less than 1 year of welding experience, and the experienced group consisted of 10 men who had been working for more than 1 but less than 5 years. Among the inexperienced workers, overhead welding resulted in EMG changes indicative of localized fatigue in the deltoid, upper trapezius, and supraspinatus muscles. Experienced welders demonstrated some adaptation but still had abnormal EMG readings for the supraspinatus muscles. The authors concluded that overhead welding places considerable amounts of strain on this muscle, which cannot be overcome by experience and training.

Petersen et al. [1977] reported similar findings in a third study. Those observed included 10 experienced workers with at least 5 years of experience and 10 inexperienced welders with less than 1 year of training. After overhead welding, all experienced welders and a few inexperienced welders (number not given) showed increased fatigue of the supraspinatus muscle. A subset of older welders complaining of shoulder pain was tested further. Clinical examination (X-ray) showed diminished strength in shoulder movements in which the supraspinatus was active, and clear signs of supraspinatus tendinitis. However, it was emphasized that the tendinitis may have been caused by long exposure or as a consequence of natural changes from age in combination with overhead welding.

Ross [1978] reported on the results of medical examinations of 926 shielded metal arc welders; all were male, had heavy engineering and shipbuilding experience, and had been observed for 6 years. These findings were compared with the results of medical examinations of 755 nonwelders who were used as controls. Chronic conditions encountered included occupational hearing loss, Raynaud's phenomenon, and Dupuytren's contracture. Raynaud's phenomenon, also called white finger disease, affected 102 (11%) of the welders, compared with 7 (1%) of the nonwelders. It was associated with the use of vibratory tools but was considered by the author to be relatively minor in nature. Dupuytren's contracture, a flexion deformity of the finger, which the author reported as not usually occupational in origin, was found in 38 (4%) of the welders and 4 (0.5%) of the controls. The author speculated that it could be caused by tightly gripping the electrode holders.

Nauwald [1980] studied knee joint changes in 100 welders (type not stated) in the shipbuilding industry. Sixty-nine of the 100 welders complained of spontaneous pains in the knee joints. These included pain during motion, pain when starting to move, pain during hypercompression of the joint, and the so-called "giving-away" phenomenon. Arthritis, proliferation of fatty tissue in knee joint, and fluid sac diseases were observed with increasing frequency in welders who were older than 25 and had a minimum exposure time of 6 years. The author stated several potential causative factors in the development of the observed knee joint diseases: (1) the static-mechanical stress on the bent knee while working, (2) the chronic, persistent pressure on the soft parts of the joint, and (3) thermal effects such as cooling due to kneeling on cold iron for an extended period of time.

C. Safety Hazards

In addition to being exposed to chemical and physical agents, welders are also exposed to potential safety hazards that may result in injury or death. Most of the injuries occur as a result of poor work practices, inadequate engineering controls, or improper or inadequate training.

Work injury data were obtained from the Supplementary Data System (SDS) of the Bureau of Labor Statistics (BLS) occupational code 680 (welders and flame cutters) for 1976-81 [BLS 1985]. In a cross analysis, the source of injury was cross-tabulated with type of accident, nature of injury, and body part. The analysis of the SDS accident/injury data was performed for the top 10 source-of-injury categories that identified tools, tasks, or equipment used by welders and thermal cutters. A total of 166,907 injuries were reported to the SDS data base from welders and thermal cutters during the period 1976-1981; 109,774 of these injuries were included in the cross analysis and reported in Table IV-9. The SDS data do not include any information on the cause of the injury.

The Bureau of Labor Statistics [1983] obtained data from 18 States on welding- and cutting-related injuries for 1,364 workers that occurred during a 5-month period in 1978. Forty-two percent of the reported injuries during this period occurred in welders or cutters who had 5 or more years of experience; 92% of these welders and cutters had received safety training in the form of classroom or on-the-job safety training or written material about welding or cutting safety measures. Arc welding or cutting was being performed when two-thirds of these injuries occurred, and 83% had received safety training in the use of this equipment. Sixty-seven percent of the reported injuries were to the eye(s); 58% of the burns to the eyes resulted from welding being performed in the nearby work area; 50% of all eye injuries occurred as a result of not wearing filtering lenses to protect the eyes.

Injury of workers by industrial welding robots has also occurred. Specific types and the number of injuries reported for welders involved in these types of processes are not available; however, this kind of information is being gathered by the Division of Safety Research, NIOSH [NIOSH 1985]. According to Percival [1984], the six main sources of hazards from industrial robots are as follows: (1) control errors caused by errors in the software, faults within the control system, or electrical interference; (2) unauthorized access to robot enclosures; (3) human error when working close to a robot; (4) electrical, hydraulic, and pneumatic faults; (5) mechanical hazards from the function of the robot (e.g., welding hazards); and (6) environmental hazards (e.g., dust, fumes, radiation). Although specific controls for these hazards are not addressed in this

Table IV-9.--Summary of SDS accident/injury profile, 1976-1981, for welders and thermal cutters (occupational code 680)[a]

Source of injury	Total number of accidents/ injuries	Accidents		Injuries		Body part injured	
		Type	Number[b]	Type	Number[b]	Body part	Number of injuries[b]
Welding equipment, electric arc	11,261	Contact with radiation, caustics, etc., NEC[c]	6,129	Welder's flash	9,517	Eye	10,463
		By absorption	3,528	Radiation effects	884	Finger	144
		Accident type, NEC	498	Burn or scald	295		
		Contact with hot objects or substances	299				
		Contact with electric current	241				
Particles (unidentified)	9,080	Rubbed or abraded by foreign matter in eyes	7,583	Scratch, abrasion	7,853	Eye	8,931
		Struck by flying object	748	Other injury, NEC	778		
		Struck by NEC	261				
Metal items, NEC	7,857	Struck by NEC	1,204	Scratch, abrasion	1,825	Eye	2,608
		Rubbed or abraded by foreign matter in eyes	1,180	Cut, laceration, puncture	1,385	Finger	1,096
		Struck by falling object	1,103	Sprain, strain	1,339	Back	941
		Overexertion in lifting objects	956	Contusion	973	Foot (not toes)	510
		Struck against stationary object	706	Burn or scald	653		
Bodily motion	7,365	Bodily reaction	3,040	Sprain, strain	6,338	Back	3,126
		Bodily reaction by voluntary motions	2,158	Dislocation	222	Knee	1,282
		Bodily reaction by involuntary motions	1,844	Inflammation or irritation of joints, tendons, or muscles	214	Ankle	989
		Rubbed or abraded by repetition of pressure	98	Nonclassifiable	158	Neck	224

(Continued)

See footnotes at end of table.

Table IV-9 (Continued).—Summary of SDS accident/injury profile, 1976-1981, for welders and thermal cutters (occupational code 680)[a]

Source of injury	Total number of accidents/ injuries	Accidents		Injuries		Body part injured	
		Type	Number[b]	Type	Number[b]	Body part	Number of injuries[b]
Floor (of a building, a scaffold, a mine, a vehicle, etc.)	5,172	Fall to the walkway or work surface	2,439	Sprain, strain	2,128	Back	1,022
		Fall on same level, NEC	924	Contusion, crushing, bruise	1,021	Knee	818
		Fall from ladder	611	Fracture	826	Multiple parts	615
		Fall from scaffold, walkway, platform, etc.	264	Nonclassifiable	441	Ankle	443
Beams, bars	4,820	Struck by falling object	1,338	Sprain, strain	1,638	Back	1,139
		Overexertion in lifting objects	1,049	Contusion, crushing, bruise	1,119	Finger	726
		Struck by NEC	561	Fracture	832	Foot (not toes)	486
		Struck against stationary object	486	Cut, laceration, puncture	519	Toe	346
		Caught in, under, or between a moving and a stationary object	220				
Nonclassifiable	4,770	Nonclassifiable	2,432	Sprain, strain	1,547	Back	1,142
		Overexertion in lifting objects	611	Nonclassifiable	946	Eye	552
		Rubbed or abraded by foreign matter in eyes	213	Contusion, crushing, bruise	379	Finger	398
				Cut, laceration, puncture	394	Abdomen	240
				Nonclassifiable	316		

(Continued)

See footnotes at end of table.

Table IV-9 (Continued).--Summary of SDS accident/injury profile, 1976-1981, for welders and thermal cutters (occupational code 680)[a]

Source of injury	Total number of accidents/ injuries	Accidents		Injuries		Body part injured	
		Type	Number[b]	Type	Number[b]	Body part	Number of injuries[b]
Pipe	3,957	Struck by falling object	962	Sprain, strain	1,421	Back	989
		Overexertion in lifting objects	909	Contusion, crushing, bruise	857	Finger	603
		Struck by NEC	451	Fracture	519	Foot (not toes)	486
		Struck against stationary object	364	Cut, laceration, puncture	488	Toe	346
		Caught in, under, or between a moving and a stationary object	174				
Miscellaneous, NEC	3,666	Overexertion in lifting objects	895	Sprain, strain	1,385	Back	939
		Struck by falling objects	512	Contusion, crushing, bruise	644	Finger	557
		Overexertion in pulling or pushing objects	212	Cut, laceration, puncture	437	Foot (not toes)	206
		Caught in, under, or between NEC	200	Fracture	289	Eye	203
Flame, fire, smoke	3,479	Contact with hot objects or substances	2,960	Burn or scald (heat)	3,073	Hand	482
		Contact with radiation, caustics, toxic and noxious substances	206	Other injury, NEC	52	Multiple parts	474
		Explosion	91	Influenza, pneumonia, bronchitis, asthma, pneumonitis, emphysema	44	Eye	314
						Finger	255

[a]Source: BLS [1985].
[b]These figures include only those for the most frequent subcategories of each major heading ("Accidents," "Injuries," or "Body part injured"); thus their totals do not match those under "Total number of accidents/injuries.
[c]Not lsewhere classified.

document, many of the measures recommended for controlling emissions generated at other welding processes can be applied to industrial welding robot operations.

Some of the specific safety hazards associated with welding processes are fires, explosions, or electric shocks. The following are case reports of injuries and fatalities resulting from such hazards.

1. Fires

The fire hazards caused by either the welding flame itself or flying sparks have been responsible for injuries and fatalities of workers [NFPA 1977; Buhrer and Brunschwiler 1978]. Fires associated with oxygen-enriched atmospheres provide dramatic examples of the risks involved when there is either enrichment of the air by oxygen in enclosed spaces or leakage of oxygen. Accidents have also been reported when air has been intentionally enriched (sweetened) before welding to purge the air of contaminants.

Three fires in oxygen-enriched atmospheres were reported by Rames [1976]. The first occurred inside a storage tank where a welder was making repairs by electric arc welding. He enriched the inside atmosphere with oxygen from a cylinder outside the tank. His assistant went inside to help instead of keeping watch outside. After 20 min, their clothing suddenly ignited, and although they succeeded in getting out of the tank, they both died on the way to the hospital. The second case report was of a welder who went down a deep well to cut a rusty suction basket from a pump. Before he descended, he fed oxygen instead of compressed air into the well because he thought there might be dangerous gases present. When he started to cut, his clothing burst into flames and he fell into the water. His assistant, who was watching, was unable to help. The welder was dead when he was removed from the well. The third case was that of a welder and his assistant who were arc welding while repairing pipelines inside a small channel. Their clothing suddenly caught fire, and even though they were being observed from the outside by others, they died before they could be rescued. Investigation of the accident revealed that they were using oxygen from the cutting equipment to sweeten the air.

The National Fire Protection Association (NFPA) [NFPA 1977] reviewed reports of several fires caused by cutting and welding equipment. During repairs of an underground missile silo, a welder struck and caused a rupture to a temporarily installed, high pressure hose containing hydraulic oil. The oil escaped as a fine mist and ignited at the electric arc. Although the fire was of short duration, it killed 53 of the construction workers trapped in the confined silo space.

The California Division of Labor Statistics and Research (CDLSR) [CDLSR 1975] also described several fires resulting from welding. An auto dismantler was using an acetylene torch to cut the metal straps holding a fuel tank in place. The tank fell to the ground and pulled off the filler spout. Sparks from the torch ignited the fuel in the tank. The dismantler sustained second-degree burns on his hands and face. In another occurrence, a man was burning and cutting scrap metal. The oxygen hose caught fire and caused the worker to drop the torch, breaking the fitting. Oxygen went up his pants leg, which ignited. In another incident, a ladle helper was holding an oxygen hose while another worker was cutting with a torch. The oxygen accumulated in the worker's glove, ignited the glove, and burned his right hand.

2. Explosions

Explosions caused by welding sparks igniting flammable or explosive materials are a potential problem associated with all welding processes. A mixture of acetylene with air containing more than 2.5% or less than 80% acetylene is explosive [Compressed Gas Association 1966].

Fire resulting from an explosion occurred in the cooling plant located in the basement of a newly erected hospital [Buhrer and Brunschwiler 1978]. A chief electrician and an electrical fitter were installing wiring for an electrical plant. The chief electrician who had on-the-job experience had not received any formal welding training. While cable supports were being welded from a ladder, sparks fell to the floor igniting a rag lying on a varnish can. An explosion occurred and both workers were immediately surrounded by flames. The welder on the ladder was able to escape. His coworker who was unable to escape suffered extensive burns.

The NFPA [1977] described several explosions caused by welding that resulted in death. In one case, a workman using a torch to cut an object on the top of a drum containing kerosene cut into the drum and the oil exploded, fatally burning him. In another case, after partially unloading a tanker of asphalt stored at a temperature of about 143°C (290°F), two workmen went to the top of the tank to straighten the pipe through which they measured the oil level. They were using an acetylene torch that ignited the leaking vapors and caused an explosion that killed both men. In another reported incident, three welders were killed as a result of an explosion that occurred while they were repairing a leak in an odor-scrubbing system. Heat from the torch had ignited flammable vapors within a connecting pipe, and the flame was propagated to the tank that contained naphthalene. The tank ruptured, killing all three workmen.

Several explosions were reported in the CDLSR description of welding accidents [CDLSR 1975]. Some of these occurred in atmospheres enriched by oxygen and some occurred when sparks caused the ignition of flammable vapors or liquids that had leaked from hoses or containers.

3. Electric Shocks

Because currents of 100 to 600 A at 30 to 60 V, either AC or DC, are used in welding, shocks to workers have resulted in falls causing serious injuries or deaths [Britton and Walsh 1940]. The usual practice in welding operations is to have the work grounded to one terminal of the power supply while the electrode holder is connected to the other terminal. Fatalities have resulted from a current passing through the body when the worker stepped on the "live" electrode, while in contact with the other terminal of the current. Careless handling or changing of electrodes has also resulted in serious injuries and fatalities.

Five welding-related deaths from electrocution occurring between 1956 and 1975 were reported by Simonsen and Petersen [1977]. One case involved a 37-year-old electric arc welder who was working in a confined space where the temperature was 35° to 40°C (95° to 104°F). He had perspired heavily and had removed one glove. The welder developed severe spasms, apparently from an electrical contact, was hospitalized, and died a short time later. Burnlike lesions were found on his lower right cheek, left thigh, and left hand.

Another welder was presumably attempting to ignite his cutting torch by drawing a spark from the welding apparatus while the transformer was operating. He suddenly fell and died a short time later. The authors provided no information on the type of protective clothing worn. Electrical malfunction of the welding machine was not a factor in this fatality.

In a third reported fatality, a 22-year-old man was welding a metal plate onto the hull of a ship while standing on a platform located about 50 cm above the water surface. He had been working for 4 hr when he lay down to weld on the edge of the plate. A large wave immersed the platform, and the welder's hand holding the welding device was submerged in water. He died from electric shock.

In 1974, a 47-year-old welder was found dead at his workplace. He had been welding on the floor of a small compartment that measured 70 x 73 x 105 cm. There was a small amount of water on the floor of the compartment. When he was found, the welding tool was in his right hand and the end of the welding electrode had slid under the face mask and up under his glasses near the left eye. At autopsy, a burnlike perforation of the median sclera of the left eye was found. In 1975, a 47-year-old man was found dead in a section of a ship where he had been welding. He was found lying on his back against the side of the ship with the welding tool in his left hand and the tip of the electrode pointing toward his throat. His helmet and mask lay beside him. It was very hot in the area where he had been working, and his clothing was soaked with perspiration. The authors stated that the welding apparatus was not defective and the maximum voltage at idle was 86.0 V. The autopsy revealed an electrical burn on the right side of the throat.