In addition, it appears that compounds other than chromium(VI) could also be active in the water soluble fractions of fumes generated from the two welding processes. This is based on the fact that when the water soluble fractions of both fumes were tested in a metabolically activated S. typhimurium mutagenicity assay, only shielded metal arc fumes lost their metabolic potency [Hedenstedt et al. 1977; Stern et al. 1982].

One 2-year carcinogenicity study has been reported for Syrian golden hamsters that were intratracheally injected with saline suspensions of stainless steel welding fumes [Reuzel et al. 1986]. Lung cancer was observed in one animal from each of the two dose groups that were intratracheally injected with shielded metal arc welding fumes. No cancers were observed in the gas metal arc fume treatment group or the calcium chromate, saline, and historical control groups. Despite the fact that there were only two cancers observed, the authors concluded that these tumors were biologically significant based on the absence of tumors in the calcium chromate (positive control) group and the concurrent and historical nonexposed control groups. However, some question exists concerning calcium chromate being considered as a positive control since: (1) no published experimental data shows the induction of any kind of cancers in hamsters when calcium chromate is intratracheally administered, and (2) the number of animals and dose used for the calcium chromate positive control group may not have been large enough to detect a positive carcinogenic response in these animals.

2. Human Toxicity

a. Pulmonary Effects

This section evaluates case reports and epidemiologic studies that document the adverse respiratory effects reported for workers who are associated with various types of welding processes. The studies are presented in order of the severity of the effects they report, beginning with those that discuss the acute effects associated with exposure to welding fumes and gases (e.g., metal fume fever and pneumonitis) and ending with studies that suggest a risk of respiratory cancer. The data from these investigations are summarized in Tables IV-2, IV-3, and IV-4. Although many of the studies have shortcomings (e.g., the absence of information on types and concentrations of specific chemical agents or on smoking habits), they collectively demonstrate the consistency of the many respiratory diseases in welders.

(1) Nonmalignant Pulmonary Diseases

(a) Metal Fume Fever

Metal fume fever is an acute respiratory disease that is usually of short duration; it is caused by the inhalation of metal oxide fumes that are typically 0.2 to 1.0 μm in particle size (Papp 1968). Although several metals are

Table IV-2.—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Metal fume fever</u>:			
Ross 1974	Shielded metal arc	Acute exposure. Covered electrode contained nickel; mixed fume composition (e.g., iron, calcium, fluoride, silica, aluminum, copper, nickel, etc.)	Tightness of chest, profuse sweating followed by metal fume fever and pneumonia a few days after exposure.
Johnson and Kilburn 1983	Torch brazing	Acute exposure from using several filler metals containing zinc, cadmium, copper, and mild steel.	Eye irritation, headache shortly after exposure followed by muscular pain, chills, chest tightness, malaise, and shortness of breath. Blood leukocyte count and body temperature increased within 24 hours of exposure. Chest radiograph indicated nodular densities.
<u>Pneumonitis resulting from metal fumes</u>:			
Patwardhan and Finckh 1976; Blejer and Caplan 1969; Winston 1971; Beton et al. 1966; Christensen and Olson 1957; Townshend 1968	Brazing or argon arc welding with silver-cadmium alloy; cutting/welding cadmium coated metal	Acute exposure to cadmium fumes (generally in poorly ventilated areas). Exposure concentrations unknown.	Respiratory distress, fever, chills, and pulmonary edema occurring over a period of several days and sometimes resulting in death.

(Continued)

Table IV-2 (Continued).--Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
Pneumonitis resulting from metal fumes:			
Jindrichova 1976	Shielded metal arc welding	Three specific groups of welders acutely exposed to various concentrations of chromium and nickel.	Respiratory distress, cough, pulmonary edema, erosion of nasal septum, chronic atrophic rhinitis.
Herbert et al. 1982	Electric arc welding	Acute exposure to aluminum and iron fume.	Diminished FEV, FVC, and total lung capacity, and chronic interstitial pneumonia.
Pneumonitis resulting from gases:			
Mangold and Beckett 1971	Silver brazing	Acute exposure to potassium fluoride and silver/copper. Poor ventilation.	Pulmonary edema.
Maddock 1970	Oxyacetylene torch	Acute exposure to nitrogen dioxide: >100 ppm. Poor ventilation in confined space.	Pulmonary edema followed by death the following day.
Molos and Collins 1957	Argon-oxygen shielded arc welding	Acute exposure to ozone: 2.6 ppm (average). No exposure to fume reported.	Respiratory tract irritation, fatigue, headaches, and shortness of breath.

(Continued)

Table IV-2 (Continued).--Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
Pneumonitis resulting from gases:			
Challen et al. 1958	Gas tungsten arc welding	Acute exposure to ozone: 0.8-1.7 ppm. No exposure to fume reported.	Respiratory irritation, eliminated when ozone concentration was reduced to 0.2 ppm.
Kleinfeld et al. 1957	Gas metal and tungsten arc welding	Acute exposure to ozone: 9.2 ppm (average). No exposure to fume reported.	Radiographs revealed diffuse peribronchial infiltration consistent with multilobular pneumonia.
Pneumoconiosis including siderosis:			
Enzer and Sander 1938	Arc welding	Chronic mixed-fume exposure for 7-12 years. Poor ventilation. No exposure data.	Lung nodulations with iron deposited around bronchi, in the lymphatic vessels and alveolar septa. No reported parenchymatous changes or fibrosis.
Stettler 1977	Arc welding	Chronic exposure to fume containing iron, chromium, manganese, and nickel from stainless steel welding. Same composition found in lung biopsy.	Two welders examined: one worker welded in open spaces while the other welded in confined spaces. Both had pulmonary fibrosis; the welder who worked in the confined spaces had severe respiratory impairment with extensive interstitial fibrosis.

(Continued)

Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Pneumoconiosis including siderosis:</u>			
Brun et al. 1972	Arc welding	Welder worked 16 years with stainless steel. Poor ventilation; no exposure data.	Dyspnea, rales, intraalveolar fibrosis, bilateral micronodular reticulation; siderophages in sputum.
Dreesen 1947	Arc welding	Chronic exposure to iron oxide, zinc, other metals. Iron oxide: >20 mg/m^3; zinc: >12 mg/m^3. Poor ventilation and confined spaces.	Siderosis diagnosed in 3% of welders and none in other workers (medical examination of 4,650 workers, 70% welders).
Marchand et al. 1964	Arc welding	No exposure data.	Pneumoconiosis radiologically diagnosed in 25 out of 402 welders (7%). Siderosis classified in 7 of the 25 welders.
Stanescu et al. 1967	Arc welding	No exposure data.	Siderosis suggestive in radiographs of 16 welders while not revealed in 13 nonwelders.
Meyer et al. 1967	Arc welding	Worked with low/high alloys and stainless steel and nonferrous metals.	Massive conglomerate fibrosis (one welder, 24 years exposure).

(Continued)

Table IV-2 (Continued).--Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
Pneumoconiosis including siderosis:			
Kleinfeld et al. 1969	Oxyfuel cutting and shielded metal arc welding	Chronic exposure to iron oxide exposures up to 1.7 mg/m^3 inside helmet and up to 12 mg/m^3 in work environment.	Radiographic examination revealed nodular shadows in lungs (8 of 25 welders) and siderosis in those welders employed longer than 20 years.
Attfield and Ross 1978	Gas metal and gas tungsten arc welding	No exposure data.	Lung opacities (up to 3 mm diameter) were noted in 8 out of 661 welders.
Levy and Margolis 1974	Oxyacetylene cutter	Welder worked 5 years in a steel foundry--respirable silica (6.82 mg/m^3) and iron oxide (19.4 mg/m^3) exposures in work area.	Radiographic examination revealed a reticular pattern in lung; pulmonary function tests revealed impairment; lung biopsy tissue revealed iron oxide and silica.
Mignolet 1950	Oxyfuel gas and arc welding, and oxyacetylene cutting	No exposure data.	Medical histories evaluated on 216 welders: 61% arc welders, 41% oxyacetylene cutters and 18% oxyfuel gas welders had abnormal radiographs with localized or generalized sclerosis.
Bronchitis/pulmonary function:			
Hunnicutt et al. 1964	Arc welding	Chronic exposure of shipyard welders. No exposure data.	Decrement (p=0.01) in FEV_1, MEFR, and MMF volumes for welders relative to unexposed controls. Welders who smoked had twice the incidence of abnormal pulmonary function than controls who smoked.

(Continued)

Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
<u>Bronchitis/pulmonary function:</u>			
Fogh et al. 1969	Arc welding	Chronic exposure of shipyard welders and some engine/boiler welders. No exposure data.	Increased symptoms of chronic bronchitis was observed for smokers in both welders and controls. Impairment of pulmonary function was found to be increased in welders who smoked from nonsmoking welders. This difference was not observed between smokers and nonsmokers in the controls.
Barhad et al. 1975	Arc welding, some oxy-acetylene torch and shielded welding	Chronic exposure of shipyard welders. Concentrations of welding fume: 6-36 mg/m^3 in welders' breathing zone and 48-92 mg/m^3 in confined spaces.	Dyspnea and wheezing ($p<0.001$) and paroxysmal dyspnea ($p<0.005$) increased in welders compared to controls.
Akbarkhanzadeh 1980	Shielded metal arc welding	Chronic exposure of shipyard welders. No exposure data.	Prevalence of chronic bronchitis increased with age, greater in welders than controls and greater among smokers.
Kujawska 1968	Arc welding	60 welders had at least 10 years of exposure, of which half had siderosis. No exposure data.	Welders with siderotic changes had lower VC and FEV_1 values when compared to other welders or controls. Chronic bronchitis more prevalent ($p<0.05$) in welders than nonexposed controls. Similar distribution of smokers and nonsmokers.

(Continued)

Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
Bronchitis/pulmonary function:			
Antti-Poika et al. 1977	Electric arc welding	157 welders employed in engineering shops had at least 3 years of exposure. Concentrations of total welding fume: 1-9 mg/m^3, 8-hr TWA.	Chronic bronchitis more prevalent ($p<0.01$) among welders than nonexposed controls.
Doig and Challen 1964; Glass et al. 1971	Arc welding	Acute exposure of welders working near degreasing tanks that contained trichloroethylene. Probable decomposition and formation of phosgene.	Respiratory distress, cough, chest constriction, breathlessness, arterial hypoxia, and impaired carbon monoxide transfer.
Sjogren and Ulfvarson 1985	Gas metal or tungsten arc welding (Group 1). Arc welding (Groups 2 and 3).	Welders placed into three exposure/job groups: Group 1: Gas metal arc welding on aluminum. 50% of ozone exposures exceeded 0.1 ppm. Group 2: Welded with covered electrodes on stainless steel. 80% of chromium(VI) exposures exceeded 20 $\mu g/m^3$. Group 3: Welded on railroad tracks. Nitrogen oxides were below 5 ppm for all 3 groups.	Respiratory symptoms more prevalent for welders in Group 1 when compared to controls, significant ($p=0.03$) with increasing exposure to ozone. Chronic bronchitis higher in all three groups when compared to controls. No differences in pulmonary function. Increasing respiratory symptoms in Groups 2 and 3 with increasing chromium exposures but no relationship with increasing total fume concentrations.

(Continued)

Table IV-2 (Continued).—Summary of studies on welding emissions and nonmalignant pulmonary disease

Disease and references	Type of welding	Exposure/study conditions	Health effects
Bronchitis/pulmonary function:			
Keimig et al. 1983	Gas metal arc welding and flux core welding	The study group was made up of 91 welders (46 nonsmokers, 45 smokers) and 80 controls (35 nonsmokers, 45 smokers). Welding of mild steel: breathing zone air samples indicated iron oxide concentrations of 1.3–8.5 mg/m^3. No detectable amounts of chromium, copper, fluoride and lead in any samples.	Welders and controls who smoked had a higher frequency of respiratory symptoms than nonsmokers. Nonsmoking welders and smoking welders, compared to respective controls, did not have significantly decreased FVC or FEV_1. Welders who did not smoke had a reported increase ($p<0.05$) in phlegm and episodes of cough and phlegm when compared to nonsmoking controls.
Oleru and Ademiluyi 1987	Shielded and manual metal arc welding	Study group made up of 67 (36.8%) of a total 182 men employed in an industry that made window and door frames from medium and high-alloy steel and aluminum. No exposure data. Authors hypothesized that airborne dust concentrations probably exceeded 5 mg/m^3 based on the amount of settled dust.	Seven cases of restrictive lung impairment were observed: 3 paint dippers, 2 aluminum workers and 2 welders. Welders given spirometric lung function tests demonstrated statistically significant ($p<0.05$) decrements in all parameters measured when evaluated over a 40-hr work week. Peak flow measurements were reduced ($p<0.05$) for welders when measured at the end of the 8-hr work shift.

Table IV-3.—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	Expected	SMR[a] (95% CI[b] or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies:</u>								
Sjogren, 1980[c]	Welders who had stainless steel welding as their main task for at least 5 years between the period 1950 and 1965 and were followed to 1977. No exposure to asbestos and welded with covered electrodes most of the time (207 out of 234 welders).	234 welders (all males) 3,735 person-years; 100% followup of subjects.	Controls: 5-year study adjusted for cause, gender, age, and year. Specific national death rates of Sweden.	3	0.7		4.4 ($p<0.03$)	No
				3	0.7		4.4 ($p<0.05$)	Yes[d]

(Continued)

[a] Standard mortality ratio.
[b] Confidence interval.
[c] Primary exposure to chromium and nickel. Pulmonary tumors observed in 3 welders: Welder A used covered electrodes on stainless steel from mid-40's; died in 1957. Welder B used covered electrodes on stainless steel from mid-40's until 1957; died in 1977 of a non-differentiated pulmonary tumor. Welder C gas-shielded from 1940 until 1969; died in 1977 of a highly differentiated adenocarcinoma. Welders A & B smoked; Welder C stopped smoking 20 years before death.
[d] It was estimated that 10% more welders smoked than did members of the control group (Swedish male population).

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	No. of cases Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
Cohort Mortality Studies:								
Sjogren, et al., 1987[e]	Follow-up study reported by Sjogren (1980). Analysis and comparison of railway track welders exposed to low concentrations of chromium (<10 mg/m^3). Both cohorts worked for at least 5 years between 1950 and 1965 and were followed until December 1984. No reported exposure to asbestos.	Follow-up of 234 welders (Sjogren 1980). 208 railway track welders. All males in both cohorts.	Controls: 5-year age categories by cause, gender, age, and calendar-year. Specific national death rates.	Cohort of 234: 5	2	249 (80-581)		No
				Cohort of 208: 1	3	33 (0-184)		No
							7.0[f] (1.32-37.3)	

(Continued)

[e] Follow-up study of 234 stainless steel welders (5324 person-years) exposed to high concentrations of chromium (Sjorgen 1980). Analysis of 208 welders (5273 person-years) exposed to low concentrations of chromium.

[f] Comparison of welders exposed to high concentrations of chromium with welders exposed to low concentrations to determine risk of developing lung cancer.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Becker et al., 1985[g]	Arc welders from 25 factories (e.g., sanitary installations, power plants and boilers) who started between 1950 and 1978 and followed to 1983.	1,224 welders (all males); 23,492 person-years. 96% follow-up of subjects.	(a) 1,694 turners (internal control) who were not exposed to nickel or chromium.	(a) Welders: 6	10		1.7 (0.7–4.0)	Yes
			(b) Total population of Germany (external control).	(b) Welders: 6	6.3	95.5 (p<0.05)		Yes
				Turners: 10	14.5	69.2 (p<0.05)		Yes

(Continued)

[g] Upward trend in the SMR (compared with German population) for welders when analyzed by time since first exposure; reached statistical significance for malignant neoplasms in last time interval (≥30 years). Characteristic of a healthy worker effect; no upward trend seen for turners. Welders used covered chromium-nickel alloyed electrodes and gas shielded with covered chromium-nickel alloyed wire.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Beaumont and Weiss 1981	Welders from the State of Washington employed in various industries, primarily shipbuilding, field construction, and metal fabrication shops.	3,247 welders who were union members for a minimum of 3 years including at least 1 day between 1950 and 1973 and followed to 1977 (43,670 person-years).	(a) U.S. death rates for white males used.	(a) 50	37.95	132 (p=0.06)		No[h]
					22.38	174[i] (p<0.001)		No[h]
			(b) 5,432 nonwelders (internal control).	(b) 39[j]			1.28 (0.89–1.84)	No[h]

(Continued)

---

[h] Internal control group (nonwelders) used to account for smoking.
[i] ≥20 years since first exposure.
[j] Excess risk of lung cancer examined by age at risk, calendar time, age started work, year started work, duration of exposure, and latency. Both age at risk and calendar time exhibited a positive trend. Duration of exposure and latency were strongly associated with lung cancer. Attributable risk: 23.1 lung cancers/100,000 welders per year (11.2–57.5).

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases		SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
				Observed	Expected			
<u>Cohort Mortality Studies</u>:								
Steenland et al., 1986[l]	Reanalysis of the Beaumont and Weiss 1981 study cohort. Cox and logistic regression analysis performed to compare lung cancer risk.	3,247 welders from the State of Washington employed at least 1 day between 1950-1973 and followed to 1977.	5,432 non-welders (e.g., pipefitters, riggers) that belonged to the same union.				1.52[k] (p=0.03) 1.29[m] (p=0.03) 1.15[n]	

(Continued)

[k] Logistic analysis indicating a statistically significant interaction observed between welding and year-first-employed for lung cancer.
[l] Analysis of welders for lung cancer risk using internal non-exposed comparison group and two types of regression analysis. A total of 137 lung cancer deaths (50 welders, 87 controls).
[m] Logistic analysis indicating a statistically significant interaction between cumulative exposure of welders and lung cancer.
[n] Cox regression analysis indicating elevated lung cancer risk among welders when analyzed by cumulative exposure.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	No. of cases Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Newhouse et al., 1985[p]	Welders, caulkers, burners, platers, and electricians who were employed at shipyards in England between 1940 and 1968 and who were followed through 1982. Occupations selected on potential exposure to welding fumes.	Welders (W): 1,027. Caulkers (C): 235. Platers (P): 557. Electricians (E): 1,670. (99.5% followup of subjects)	Population rates for males in the Newcastle area of England.	W: 26	22.9	113 (80–157)[o]		No[o]
				C: 12	5.2	232 (133–374)[o]		No[o]
				P: 12	12.1	100 (57–161)[o]		No[o]
				E: 35	33.6	104 (75–133)[o]		No[o]

(Continued)

[o] Note: 90% confidence limits on SMR's. No information on smoking habits.

[p] 13 deaths due to mesothelial tumors: 9 among electricians, 2 among platers, and 1 each among welders and caulkers (excluded from lung cancer cases). When welders and caulkers (groups with the highest potential to welding fume) were combined, lung cancer deaths were statistically significant (no SMR given). Deaths due to pneumonia were elevated for welders and caulkers with SMR's of 184 (100–314) and 165 (30–525), respectively.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Polednak, 1981[q]	Welders at 3 nuclear facilities at Oak Ridge, Tenn., who were hired between 1943 and 1974 and followed through 1974. Subgroup of 536 welders exposed mostly to nickel oxides and fluoride. Subgroup of 523 welders performed only tungsten inert gas (90%) and shielded metal arc (10%) welding.	Total of 1,059 white male welders (23,674 person-years); 92% follow-up of subjects.	U.S. white males.	All welders				
				17	11.37	150 (87-240)		No
				Welders exposed to nickel oxides				
				7	5.65	124 (50-255)		No
				Other subgroup of welders				
				10	5.71	175 (84-322)		No

(Continued)

[q] The subgroup of welders exposed to nickel oxides between 1975 and 1977 had a TWA concentration of 0.57 mg/m^3 nickel. The other subgroup of welders monitored between 1973 and 1977 had 3 samples that exceeded 0.1 mg/m^3 nickel and 21 samples that were below the limit of detection. Of 10 samples collected for chromium in this subgroup, all but one (2.22 mg/m^3) were below 1.0 mg/m^3. Most TWA's for iron oxide in both subgroups were below 5 mg/m^3. Welders who worked 50 weeks or more with nickel-containing electrodes showed 5 lung cancer cases compared with 2.66 expected.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	No. of cases Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies</u>:								
Dunn and Weir, 1968	Multiple occupations followed prospectively (deaths between 1954 and 1962). Follow-up of study group until death, 70th birthday, or Dec. 31, 1962 (study completion).	Total study population of 68,153 men from a number of unions in California; 482,658 total person-years. Welders: 81,389 person-years. Person-years determined from ages 35-69.	Internal comparison.	49	46.5[t]	Not reported	1.05 NS[s]	Yes

(Continued)

[r] Expected number of deaths calculated with rates specific for age and amount of smoking observed for all occupational groups combined. Smoking histories gathered through a questionnaire. Only 1% of population had died.

[s] Not statistically significant.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
Cohort Mortality Studies:								
Puntoni et al., 1979[t]	Shipyard workers analyzed by 19 occupational groups (including electric and gas welders). All workers who were employed or who had retired as of 1960, 1970, and 1975 and all who were dismissed or retired during 1960-75. Followed for mortality until 1975.	Electric welders: 2,106 person-years Gas welders: 1,723 person-years.	(a) Male staff of St. Martino Hospital, Genoa, Italy.	(a) Gas welders: 4	1.89		2.12 NS	No
				Electric welders: 3	1.18		2.54 NS	No
			(b) General male population of Genoa, Italy (same study time-period.	(b) Gas welders: 4	3.20		1.25 NS	No
				Electric welders: 3	1.88		1.60 NS	No

(Continued)

[t] No smoking or age adjustment; poor cohort definition.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases: Observed	No. of cases: Expected	SMR (95% CI or p value)[u]	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cohort Mortality Studies (Malignant neoplasms)</u>:								
Ott et al., 1976	All employees at a chemical facility (except those exposed to arsenicals or asbestos) as of March 1954 and followed until 1973. Analysis performed on 15 job categories (including welders/lead-burners)	Total study group: 8,171. Subcohort A hired before 1950: 5,994. Subcohort B hired between January 1950 and March 1954: 2,177. Total welders: 180.	U.S. white males.	Subcohort A: 256	259.2	99		No
				Subcohort B: 28	35.9	78		No
				Welders: 12	7.4	162[v]		No

(Continued)

[u] SMR's reported for malignant neoplasms.
[v] Note: 2 of the 12 malignant neoplasms for welders were at respiratory sites. No CI or p values given, but reported as not being statistically significant. No exposure data.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases		SMR (95% CI or p value)	Odds ratio (95% CI or p value)	Controlled for smoking
				Observed	Expected			
<u>Cross-sectional Mortality Studies</u>:								
Menck and Henderson 1976[w]	2,161 death certificates (1968-70) of white males aged 20-64 (Los Angeles Co.) and pooled with all 1,777 incident cases of lung cancer for white males, same age group, reported to the Los Angeles Co. Cancer Surveillance Program for 1972-73.	Welders: 21 deaths and 27 incident cases of lung cancer.	Estimated from 1970 census, Los Angeles County occupational data. Each occupation assumed to have same probability of lung cancer as entire population; estimated 15,300 welders in L.A. county.	48 (mortality and incident cases)	Not reported		1.37 ($p<0.05$)	No

(Continued)

[w] Age adjustment was not complete. No exposure data. Analysis performed by job category and industry.

Table IV-3 (Continued).—Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases Observed	Expected	PMR[x] (95% CI or p value)[u]	Odds ratio (95% CI or p value)	Controlled for smoking
<u>Cross-sectional Mortality Studies</u>:								
HMSO 1978	English and Welsh welders' and burners' deaths recorded during 1968-69.	128,000 welders; approx. 256,000 person-years. Job-titles: Gas, electric welders; cutters, brazers.	Age adjusted general population.	246	192	151 (p<0.01)		No
						116[y] (p<0.01)		Yes

(Continued)

---

[x] Proportional mortality ratio.
[y] SMR adjusted for the welder's incidence of smoking, which was 22% higher than that expected in the general population.

Table IV-3 (Continued).--Summary of studies on welding emissions and mortality from respiratory cancer

Type of study and references	Description of study	Number of welders studied	Control group	No. of cases		PMR (95% CI or p value)[u]	Odds ratio (95% CI or p value)	Controlled for smoking
				Observed	Expected			
<u>Proportional Mortality Study</u>:								
Milham, 1983	Occupation and cause of death on 429,926 Washington State white males for 1950-79.	Welders and flame cutters. Total deaths: 2,124	All Washington State deaths.	153	114	126[z] (p<0.01)		No
						135[aa] (p<0.01)		No

[z] Respiratory system cancers.
[aa] Tracheal, bronchial, lung cancer. No exposure data.

Table IV-4.—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study[a]	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI[b])	Controlled for smoking
Blot et al., 1978	Investigated high rate of lung cancer among white male residents of 11 county coastal areas in Georgia. Cases identified from one large hospital since 1970, 3 other hospitals during 1975-76, and ascertainment of death certificates for lung cancer within the counties.	458 cases of primary lung cancer identified of which 11 had worked as welders.	553 controls from hospital admissions and from death certificates for diagnoses other than lung or bladder cancer or chronic lung disease. Two controls for each case matched closely by sex, race, age, residence, and current vital status.	11 welders	20 controls	1.6[c] (1.1-2.3) (p=0.006) 0.7[d]	Yes

(Continued)

[a] Questionnaire given to next of kin to determine place, type, and length of employment for any job held more than 6 months. Risk for lung cancer increased with smoking and working in a shipyard. Interviews completed for 89% of lung cancer cases and 87% of the controls. Excess risk seen for other shipyard workers but not welders or riggers.
[b] Confidence interval.
[c] Those ever employed in a shipyard; number of cases and controls not given.
[d] Crude relative risk for welders and riggers.

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Gottlieb, 1980[e]	Assessment of death certificates (1960-75) for Louisiana to determine deaths from lung cancer primarily among people employed in petroleum mining and refining industries.	8 cases of lung cancer among welders employed in the petroleum industry. 200 cases of lung cancer identified for all occupations within the petroleum industry.	170 controls employed in the petroleum industry.	All workers in petroleum industry			
				200 lung cancers	170 controls	1.19 (1.05-1.35)	No
				Welders in petroleum industry			
				All welders:			
				8 welders	2 controls	1.54 (p<0.09)	No
				Welders <60 yrs. of age at death:			
				5 welders	1 control	1.89 (0.48-7.37)	No
				Welders >60 yrs. of age at death:			
				3 welders	1 control	0.93 (0.25-3.46)	No

(Continued)

[e] Excess of lung cancer mortality among welders in the petroleum industry was not observed across all industry categories. Mean age of death for these cases was several years older than that for controls.

Table IV-4 (Continued).--Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Gerin et al., 1984[f]	Case-referent study of 12 cancer sites and possible occupational exposures. Male population aged 35-70 years in Montreal, Canada from Oct. 1979 to June 1982. Determined cancer risk based on case-ascertainment in 17 hospitals.	32 welders: 21 with nickel exposure; 11 without nickel exposure. 58 nonwelders with nickel exposure.	General populations elected from electoral rolls with age-distribution comparable.	All welders			
				32	12	2.4 (1.0-5.4)	Yes
				Welders with nickel exposure			
				21	10	3.3 (1.2-9.2)	Yes
				Welders without nickel exposure			
				11	2	1.2 (0.1-9.4)	Yes
				Nonwelders with nickel exposure			
				58	19	2.9 (1.3-5.7)	Yes

(Continued)

[f] Occupational histories evaluated and potential exposures assigned to physical and chemical agents. Ethnic group, socioeconomic group, and smoking habits ascertained. Potential exposure to nickel and compounds was assigned to 79 out of 1,487 cases. Potential exposure to chromium and nickel was highly correlated--78 out of the 79 cases also had chromium exposure. Risk highest among welders exposed to nickel (mainly among stainless-steel welders).

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Breslow et al., 1954[g]	Determined occupational history and tobacco use of lung cancer patients. 518 patients (493 males) observed during 1949-52 in 11 California hospitals. Analyzed by occupation (minimum of 5 years employed in a particular job).	Ten cases that were classified as being employed as welders and flame cutters. Four cases of sheet metal workers who did welding.	Patients admitted to the same hospital as the cases, matched for age (within 5 years), sex, and race. Patients who did not have cancer or chest disease.	Welders			
				10	1		Yes
				Welders/sheet metal workers			
				14	2	1.56[h]	Yes

(Continued)

[g] Questionnaire given to cases and controls to determine occupations, potential exposure to toxic materials, and smoking habits. 93% of the lung cancer patients and 76% of the controls smoked. All 14 welders/sheet metal workers with lung cancer smoked.

[h] By applying the proportion of welders/sheet metal workers among total cases and controls in each smoking category, an expected number of welder cases was estimated to be 9, giving an observed/expected ratio of 14/9, or 1.56.

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Olsen et al. 1984[l]	Association between laryngeal cancer and exposure to welding fumes. Patients less than 75 years of age with cancer of the larynx selected in Denmark during March 1980 to March 1982.	271 laryngeal cancer patients of which 42 were exposed to welding fumes. Of the 42, 12 were exposed to fumes from stainless steel.	Controls (971) matched to cases according to residence, sex, and possible date of birth (from the municipal person register in which the case was listed).	Total larynx cancer; 271(12[i])	971(30[j])	1.3	Yes (0.7–2.7)[k]
				Glottic cancer: 176(8[i])	971(30[j])	1.3	Yes (0.6–3.1)[k]
				Supraglottic cancer: 79(2[i])	971(30[j])	0.7 (0.2–3.2)[k]	Yes
				Subglottic cancer: 11(2[i])	971(30[j])	6.7 (1.0–33.3)[k]	Yes
				Unclassifiable site of origin: 5(0[i])	971(30[j])	—	Yes

(Continued)

[i] Number exposed to stainless steel welding fume.
[j] The 42 of the 271 cases exposed to welding fumes had a statistically significant OR of 6.3 (95% C.I.=1.8–21.6) for the subglottic area of the larynx.
[k] Adjusted relative risks (age, average alcohol and tobacco consumption) and 95% confidence intervals.
[l] Data collected from questionnaires on occupation, possible exposures, use of tobacco and alcohol. Medical records also used for cases.

Table IV-4 (Continued).—Summary of case control studies on welding emissions and respiratory cancer

References	Description of study[m]	Number of welders studied	Control group	No. of cases	No. of controls	Odds ratio (p value or 95% CI)	Controlled for smoking
Schoenberg et al. 1987	Investigate lung cancer risk among white males from six geographical areas of New Jersey. Risk estimates determined by job title or industry job title category.	763 white males with histologically confirmed primary cancer of the trachea, bronchus, and lung.	900 white males from same geographical area in New Jersey.	All Welders:[n]			
				33	18	3.8 (1.8 - 7.8)	Yes
				Welders with no asbestos exposure:[n]			
				17	11	2.5 (1.1 - 5.5)	Yes

[m] Personal interviews of all cases and controls, or next of kin, were conducted to collect demographic data, personal and environmental risk factors, smoking history, and diet. Industry and job title information coded with 1970 census index system; 42 job title categories and 34 industry job title categories were chosen for analysis.

[n] Welders were identified as an industry job title category within shipbuilding workers.

capable of causing this disease, exposure to zinc oxide has been the most common cause in welders (Drinker 1922; Drinker et al. 1927). The clinical signs and symptoms of metal fume fever resemble those of an upper respiratory infection such as influenza, acute bronchitis, or pneumonia, or an upper gastrointestinal infection (Papp 1968). Chills, shivering, trembling, nausea, and vomiting may occur (Rohrs 1957). The attack usually lasts 6 to 12 hr and in some instances up to 24 hr. Weakness and mild prostration follow but recovery is usually complete. With repeated exposure, an increased resistance develops but this apparent tolerance is lost within a short time (e.g., during a weekend). The attacks tend to be more frequent and prevalent on Mondays (Drinker 1922; AGA 1978).

Although other reports exist, the studies of Ross [1974] and Johnson and Kilburn [1983] are typical examples of symptomatic effects reported in welders. Ross [1974] reported a case of metal fume fever in a shielded metal arc welder exposed to mixed fumes. Although the covered electrode contained primarily nickel, the fume contained iron, calcium, fluoride, manganese, silica, titanium, aluminum, copper, nickel, and traces of other metals. The welder experienced a severe headache and felt cold and shivery. The next day he experienced tightness of the chest, profuse sweating, and unusual thirst. Chest examination revealed wheezing. His temperature varied between 99.5° and 101.5°F (37.5° and 38.6°C). On the basis of occupational history and clinical findings, he was diagnosed as having metal fume fever complicated by pneumonia and was removed from further exposure. Two months later he was completely recovered and returned to work.

Johnson and Kilburn [1983] described the illness of a 30-year-old male Caucasian who had welded for 9 years and who became ill following torch brazing. Several filler metals that contained zinc, cadmium, copper, or mild steel were used in the process. To assist in the diagnosis, the welder was asked to braze with a silver-based filler metal containing 24% cadmium. Shortly after he started to weld, he complained of eye irritation and headache. The worker's blood leukocyte count increased 6 hours after exposure and peaked at 13 hours (increase not reported). Nine hours after onset of exposure, he developed muscular pain, chills, feverish feelings, headache, backache, chest tightness, malaise, and shortness of breath. Ten hours later, his body temperature rose and peaked at 100°F (37.7°C) for about 13 hours. A chest radiograph taken 13 hours after exposure indicated the presence of nodular densities that were not apparent in radiographs taken before exposure or after recovery (time of examination not given). As a result of these observed effects, the welder discontinued brazing with silver-based filler metals; a 6-month follow-up examination revealed no further subjective symptoms. The authors concluded that cadmium, which was present in the silver-based filler metal the welder was using, was the causative agent in this case of metal fume fever.

(b) Pneumonitis

Pneumonitis and pulmonary edema have been frequently reported among welders who use various types of welding processes (e.g., gas and shielded metal arc, silver brazing, and oxyacetylene) in which exposures to the following have been identified: nitrogen dioxide (Maddock 1970; Mangold and Beckett 1971), ozone (Molos and Collins 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), and aluminum and iron fumes (Herbert et al. 1982).

(i) Exposure to Metal Fumes

Cases of acute cadmium fume pneumonitis and death have been reported among welders who were exposed to cadmium fumes by either brazing with silver-cadmium alloy or 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 the death of a welder who was cutting cadmium-plated bolts with an oxyacetylene torch in a confined space. Although exposure measurements for cadmium fumes were not taken, the authors estimated that exposure to cadmium oxide may have averaged 8.6 mg/m^3 based on the amount of cadmium oxide found in the welder's lungs during a postmortem examination.

Patwardhan and Finckh [1976] reported on another fatality that occurred in a 38-year-old man who was exposed to cadmium fumes while welding handles onto cadmium-plated drums. No respiratory protection or local exhaust ventilation was used. He developed respiratory distress, fever, and chills the first night after exposure. On the third day of his illness, he was admitted to the hospital, where chest X-rays revealed heart enlargement and pulmonary edema. He died of cardiac arrest approximately 3-1/2 days after exposure to cadmium fumes. Postmortem examination revealed lung changes consistent with pulmonary edema and diffuse congestion of alveolar capillaries. The liver contained 0.23 mg cadmium and the lungs contained 0.15 mg cadmium per 100 g of wet tissue.

Townshend [1968] reported on a 4-year evaluation of a 51-year-old welder who had suffered from acute pneumonitis following exposure to fumes from the welding of a silver-cadmium alloy. On the day of the incident, the welder had been using an argon arc to weld plates composed of an alloy of 91% silver and 9% cadmium. The night after exposure, he developed a burning pain in the chest, dyspnea, and dry cough and was hospitalized. The first chest radiograph was taken 23 days after the incident and showed extensive bilateral shadows, suggesting severe pulmonary edema. Eight weeks after the incident, extensive patchy shadowing was still evident. For 6 months after the exposure, lung function tests showed a progressive improvement in the forced vital capacity (FVC) to just under 80% of the predicted value, after which there was no further improvement. After 4 years, the chest X-ray showed faint nodulation. No information on smoking habits or exposure concentrations were reported.

Jindrichova [1976] and Herbert et al. [1982] reported on pneumonitis that occurred in welders exposed to fumes composed of various types of metals. Jindrichova [1976] used nose, throat, and neurologic examinations and chromium determinations from the urine to study 31 welders who welded with shielded metal arc on metals containing chromium. These welders were compared with 26 workers who were not exposed to welding fumes or chromium. All welders were divided into three groups. Group 1 consisted of 9 welders who spent about 13% of their time working with electrodes containing chromium. Group 2 consisted of 11 welders who spent half of their time using electrodes containing either 18% chromium and 9% nickel, or 23% chromium and 19% nickel. Group 3 consisted of 11 welders who used electrodes containing 19% chromium and 9% nickel for 70% of their welding time. Welders in Group 3 were exposed to a concentration of 0.75 mg/m^3 of chromium (0.62 mg/m^3 soluble chromium[VI]) oxide measured inside a container (1.1 x 3.3 m) that had no local exhaust. The same work performed with local exhaust ventilation produced a chromium concentration of 0.16 mg/m^3 (0.12 mg/m^3 soluble chromium(VI) oxide. No exposure data were given for Groups 1 and 2, but chromium exposures for Group 2 were reported to be the same as for the control group. Group 1 had no evidence of chronic bronchitis, but one welder had a chronic atrophic rhinitis with acute nosebleeds. In Group 2, one welder with 25 years of experience had pulmonary fibrosis associated with siderosis. In Group 3, all of the welders had coughs and respiratory problems. Seven of the 11 welders smoked. In Group 3, erosion of the nasal septum was found in 35% of the welders, atrophic rhinitis in 54%, pharyngitis in 45%, chronic laryngitis in 11%, and bronchitis in 72%. The findings of nasal erosion in Group 3 were consistent with chromate-induced lesions. Concentrations of chromium in urine (122-128 μg/liter of urine) for welders in Group 3 were significantly higher than either the control group or Groups 1 and 2 (concentrations not reported). Although these differences were reported to be statistically significant, no statistical methods were discussed.

Herbert et al. [1982] described chronic interstitial pneumonitis in a 35-year-old male electric arc welder who had been employed as a welder for 16 years. A biopsy of the lung revealed unspecified quantities of iron and aluminum particles and occasional asbestos bodies. Chest X-rays revealed bilateral basal infiltrates with a more discrete opacity on one side. Lung function tests showed diminished forced expiratory volume (FEV), FVC, and total lung capacity. The welder had smoked for a short period but had not smoked for the past 20 years. No exposure data were reported.

(ii) Exposure to Gases

Cases of pneumonitis and acute pulmonary edema in welders have been attributed to the inhalation of nitrogen dioxide [Maddock 1970; Mangold and Beckett 1971] and ozone [Molos and Collins 1957; Kleinfeld et al. 1957; Challen et al. 1958]. Mangold and Beckett [1971] reported on two silver brazers who were assembling a cupronickel firemain in the overhead of a 2- by 3- by 4.6-m storage compartment aboard a ship. The workers used a "silver solder" containing 80% copper, 15% silver, and 5% flux. The flux contained 27% potassium fluoride and 72% potassium borate. No local exhaust ventilation was used. Respiratory irritation forced the men to stop working after 30 min, and both were hospitalized 6 to 8 hr later with acute pulmonary edema and lung damage. One worker returned to work in a few days, whereas the other retired because of respiratory impairment. Reconstruction of the event indicated that no cadmium-bearing solders were used but that nitrogen dioxide concentrations increased from 0.38 to 122 ppm in 30 min.

Maddock [1970] reported a fatality resulting from pulmonary edema in a boilermaker who used two oxyacetylene torches with multiple jets to repair a rudder post in an enclosed compartment. He worked for several hours without complaint but developed a cough that evening. The worker was admitted to a hospital and died the following day. Death was attributed to pulmonary edema resulting from nitrogen dioxide poisoning. Reconstruction of the event revealed that a blower had dispersed the fumes throughout the compartment instead of ventilating it. The nitrogen dioxide concentration was found to exceed 20 ppm within 3 min of lighting the torches. The boilermaker had been exposed to nitrogen dioxide at an estimated concentration greater than 100 ppm.

Case reports described by Molos and Collins [1957], Kleinfeld et al. [1957], and Challen et al. [1958] document how pneumonitis can occur from the inhalation of ozone during argon-oxygen shielded and gas metal arc welding. Molos and Collins [1957] described respiratory irritation in a welder who performed argon-oxygen shielded gas metal arc welding on mild steel tanks using a mixture of 98% argon and 2% oxygen. From time to time, the welder and other workers complained of respiratory and eye irritation. Occasionally, the irritation became so severe that welding had to be discontinued. The welder continued to complain of discomfort and described symptoms of chest cramps, fatigue, headaches, impaired appetite, shortness of breath, difficulty in sleeping, and a persistent cough with occasional blood-tinged sputum. The mean ozone concentration was 2.6 ppm during welding activities. Substitution of pure argon or carbon dioxide eliminated worker complaints, but the resulting welds proved to be unacceptable and gas shielded metal arc welding was discontinued.

Pneumonitis was also reported by Kleinfeld et al. [1957] in eight welders who used gas metal and gas tungsten arc welding machines that were located in a corner of a room measuring 60 by 27 by 3 m. No supplementary ventilation was provided. The work was performed on various metal parts that contained nickel. The ozone concentration in the breathing zones of the welders was 9.2 ppm; nickel carbonyl and oxides of nitrogen were not detected. A trichloroethylene degreaser was located about 15 m from the welding area, but air measurements were negative for phosgene, a photodecomposition product of trichloroethylene. One welder was admitted to a hospital with pulmonary edema an hour after leaving work. Chest X-rays revealed diffuse peribronchial infiltration consistent with multilobular pneumonia. He remained in critical condition for 2 days with persistent pulmonary congestion, and he recovered after 2 weeks. Two of the eight welders developed dyspnea, and X-ray examination revealed scattered radiographic densities over both lung fields. Both workers were hospitalized and recovered within 9 days. Four of the remaining five welders complained of severe headaches and throat irritation.

Challen et al. [1958] also described symptoms of upper respiratory tract irritation in 11 of 14 welders who were exposed to ozone at concentrations of 0.8 to 1.7 ppm while performing gas tungsten arc welding on aluminum. These symptoms ceased when the concentrations of ozone were reduced to approximately 0.2 ppm; no mention of aluminum concentration was made.

(c) Pneumoconiosis, Including Siderosis

In 1936, clinical, radiographic, and pathologic changes in welders' lungs were first described by Doig and McLaughlin [1936]. They reported nodulations in the lungs of eight electric arc welders employed for 7 to 12 years. Similar findings were reported 2 years later [Enzer and Sander 1938] on a group of 26 electric welders who used bare metal electrodes and were exposed to iron oxide. Microscopic examination of a lung tissue biopsy from 5 of the 26 welders revealed no parenchymatous changes or fibrosis, but it did reveal a large quantity of iron deposited in the bronchi, the lymphatic vessels, and the alveolar septa--a condition that is characteristic of siderosis.

Numerous other reports described similar findings of asymptomatic, benign, and radiologically detectable lung changes attributed to the deposition of iron oxide fume particles in the lung (Britton and Walsh 1940; Sander 1944; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950). Although no exposure conditions were reported in these studies, the respiratory effects noted were in electric welders who were employed before 1950, when bare metal electrodes were primarily used.

To a large extent, bare metal electrodes have been replaced by covered electrodes. In addition to iron, covered electrodes often contain silicon, silicates, fluorides, titanium, manganese, copper, and other metals. With the increased use of covered electrodes, there have also been increases in reports of fibrosis, respiratory impairment, and active lesions at the site of accumulation of iron particles in the lungs. The following reports are representative of such observations in welders exposed to fumes of mixed composition.

Dreesen et al. [1947] reported an investigation on the health status of arc welders in steel ship construction from seven shipyards. Medical examinations were made of 4,650 workers, 70% of whom were welders. Less than 6% of the welders had more than 3 years of shipyard experience. The study population was divided into three groups: welders (Group 1); persons who did not have a clearly defined welding or nonwelding work history (Group 2); and nonwelders, including electricians, machinists, and sheet metal workers who did not have an exposure to welding fumes (Group 3). Arc welder's siderosis was diagnosed in 61 (3%) of the welders in Group 1 and in 10 (3%) of the persons in Group 2. All welders in Group 1 had a lower mean systolic blood pressure that was unrelated to age and no appreciable difference in the hematocrit and erythrocyte sedimentation rate. Approximately 25% of the welders had slag burns or scars. Welders (Group 1) had approximately the same visual acuity as those persons in Groups 2 and 3 when the data were adjusted for age. Conjunctival irritation was slightly more prevalent among welders when compared to the other two groups. Greater incidences of nasal congestion, pharyngitis, and upper respiratory symptoms were reported in welders from Group 1, with tobacco-using welders in this group showing even greater incidences; however, these differences were not reported to be statistically different when compared to those persons in Groups 2 and 3. In the chest X-rays of welders, a slight increase in lung field markings was observed as length of welding experience increased.

A total of 1,761 welding fume samples were collected and analyzed for iron and total fume. Zinc was evaluated in 278 and lead in 25 of these samples. Iron fume concentrations in excess of 20 mg/m^3 (>30 mg/m^3 expressed as ferric oxide) were found in all welding locations. The highest average iron and total fume concentrations were found in confined spaces where no ventilation was installed. Zinc concentrations in excess of 12 mg/m^3 (>15 mg/m^3 expressed as zinc oxide) were reported. No exposure data were given for total fume or lead.

To determine the frequency of siderosis, Mignolet [1950] examined and assessed the medical histories of 216 workers who were classified into the following groups: 32 oxyfuel gas welders, 99 oxyacetylene cutters, and 85 arc welders. These groups were compared with 100 workers selected from other occupations; the types of occupations and their potential for exposure to welding fumes were not stated. The number of abnormal X-rays was much higher among arc welders (61%) than among the oxyacetylene cutters (41%), the oxyfuel gas welders (18%), and the comparison group (17%). The changes included pleural adhesions, distinct diffuse sclerosis, and enlarged hilar shadows. The changes were attributed to the inhalation of iron oxide and other metals from the coverings of electrodes. In all cases, the siderosis was a localized sclerosis, not granular. Based on these findings, the author concluded that arc welding was more hazardous than oxyacetylene cutting and oxyfuel gas welding.

Marchand et al. [1964] and Attfield and Ross [1978] have likewise reported on the radiological examination of arc welders. Marchand et al. [1964] reported on the incidence of pneumopathy in 402 arc welders. Of this total, 192 had worked for 5 to 10 years, 137 had worked for 11 to 15 years, 54 had worked for 16 to 25 years, and 19 had worked for more than 25 years. Pneumoconiosis was radiologically demonstrable in 25 (7%) of the 402 welders, with 13 of the 25 cases found in the group that had worked for 11 to 15 years (the remaining 12 cases not identified). Of the 25 cases of pneumoconiosis, 7 (6 of which were in the group exposed for 11 to 15 years) were classified as siderosis.

Attfield and Ross [1978] studied radiological abnormalities in 661 electric arc welders who were engaged in many types of arc welding, including gas metal arc and gas tungsten arc processes. No exposure data were given, but 264 (40%) of the welders said they had worked near locations where asbestos was being used. Results from radiological examination of the welders indicated that 53 (8%) of them had small rounded lung opacities. Of those 53 welders, 41 (78%) had opacities that measured from 1.5 to 3 mm in diameter. One film showed lung opacities with diameters of 3 to 10 mm, while the balance of the films revealed opacities that ranged from just visible up to 1.5 mm in diameter.

The clinical findings reported by Meyer et al. [1967] of a 55-year-old arc welder who had been employed at a shipyard for 24 years were consistent with the findings previously reported by Dreesen et al. [1947] on other shipyard welders. The welder had worn a welding helmet only intermittently and frequently worked in confined areas. Both ferrous (cast, zinc-coated, and stainless) and nonferrous (aluminum, cupronickel, copper, brass, and bronze) welding materials were used. All electrodes apparently were covered. For 8 to 10 years, the welder's chest X-rays demonstrated mottling, and a lung lobectomy revealed dark pigmentation on the visceral pleural surface. The iron concentration (10 μg/ml of tissue) was 20 times the normal amount, and the silica concentration (2.8 μg/ml of tissue) was 30% of the total mineral content. Mild functional impairment was noted in the following pulmonary function parameters (% decrease from predicted values): vital capacity (VC), 4%; inspiratory capacity (IC), 15%; residual volume (RV), 52%; and functional residual capacity (FRC), 29%. A massive conglomerate fibrosis was diagnosed. Tuberculosis was suspected but not confirmed because lung cultures were not taken. The pulmonary changes were attributed to the iron and silica in the electrode coatings.

Levy and Margolis [1974] described the case of a 35-year-old man with siderosilicosis of the lung, diffuse interstitial fibrosis, and atypical alveolar epithelium associated with cancer of the lung. The subject was employed as an oxyacetylene cutter in a steel foundry for 5 years; he wore a welder's helmet for eye protection but used no specific respiratory protection. The torch-cutting was performed approximately 4 m from sandblasting operations. Within the work area, the concentration of respirable silica was reported to be 6.82 mg/m^3 and the quantity of iron oxide was 19.4 mg/m^3. The welder had no previous occupational exposure to fibrogenic dusts. A lung X-ray revealed a fine reticular pattern in both lung fields. Pulmonary function studies indicated an obstructive and restrictive ventilatory impairment accompanied by arterial hypoxemia and compensated respiratory alkalosis. X-ray diffraction analysis of lung biopsy tissue revealed iron oxide and silica.

A lung biopsy analysis reported by Brun et al. [1972] of an arc welder who had worked for 16 years on stainless steel in an area with poor ventilation indicated the presence of diffuse fibrosis. Prior medical history revealed that he had suffered dyspnea combined with an asthma-like bronchitis. Examination at the time of the report revealed rales at both lung bases, fine bilateral micronodular reticulation, and the presence of numerous macrophages laden with ferric oxide (siderophages) in the sputum. Respiratory function tests revealed a moderate respiratory deficit: vital capacity (VC) was 73% of the predicted value, and the forced expiratory volume in 1 second (FEV_1) was 65% of the predicted value. Microscopic examination of biopsy material revealed intra-alveolar fibrosis. Numerous histiocytes and macrophages filled with iron were present in the fibrositic wall.

Stettler et al. [1977] reported two cases of siderosis in which the severity of disease appeared to be associated with the welding fume composition. One worker arc welded primarily in open spaces, whereas the second worker arc welded primarily in confined spaces. The authors did not state the age of the workers, the length of employment, or the base metal(s) welded by the two workers. Lung biopsy specimens from both welders, and air samples from the workplace environments were analyzed by electron microscopy using energy dispersive X-ray analysis to determine the chemical composition of the observed particulate matter. The majority of particles in the lungs of both welders were determined to be from stainless steel welding fumes and were comprised mostly of iron with some chromium, manganese, and nickel. In addition, silica, aluminum, and various silicate particles were found in each biopsy preparation. The same types of particles were also found in air samples collected at the worksite during arc welding operations. Although both welders were considered to have siderosis, the first welder had moderate lung disease with minimal interstitial fibrosis, while the second welder had severe respiratory impairment with extensive interstitial fibrosis. The authors concluded that the severity of the disease in the second welder may have been due to the concentration of aluminum particles found in this welder's lungs, which was six times that of the other welder. The authors attributed this increase to his working in a confined space.

Stanescu et al. [1967] examined 16 arc welders (12.1 years average exposure) who had chest X-rays suggestive of siderosis and who had more than 7 years of experience. He found that seven suffered from exertional dyspnea. Although spirometric values (i.e., VC, FEV_1, total lung capacity [TLC], and RV) were generally within normal limits, the authors found a statistically significant ($p<0.05$) decrement in pulmonary compliance when these 7 welders were compared with 13 workers who were not exposed to welding fumes. The authors attributed this decrease either to iron deposits per se or to associated fibrosis caused by other chemical exposures. No mention was made as to whether or not the welders' smoking habits or ages were considered.

In contrast to the decrements in pulmonary compliance found in welders by Stanescu et al. [1967], Kleinfeld et al. [1969] found no differences between welders and a comparison group when they were given a series of pulmonary function tests. Twenty-five welders were compared with a group of 20 men who resided in the same area but who were not exposed to welding fumes. Occupational histories were obtained from all workers in the study, and clinical examinations were performed, including chest X-rays. The average age of the welders was 48.8 years, and the average age of the comparison group was 46.7 years. Fifty-six percent of the welders and 55% of the comparison group were smokers. The average work experience of the welders was 18.7 years, with a range of 3 to 32 years. Their work included oxyfuel cutting and shielded metal arc welding.

Eight (32%) of the 25 welders showed lung changes on X-rays that were characterized by reticular nodular shadows in both lungs. These changes were absent in members of the comparison group. Pulmonary function values, including FEV, FEV_1, RV, and TLC, were normal for both groups. In addition, none of the clinical tests showed statistically significant differences between welders exposed for more than 20 years and those exposed for fewer than 20 years. At the time of the study, environmental sampling was conducted at the sheet metal fabrication facility where the welders were employed. Concentrations of iron oxide ranged from 0.65 to 1.7 mg/m^3 inside the welders' face shields and from 1.6 to 12 mg/m^3 outside the face shields. Exposure to other fume constituents was not reported. Eight years before the study and just before an improved ventilation system was installed, iron oxide concentrations had ranged from 30 to 47 mg/m^3 in the breathing zones of other welders working at the facility.

(d) Bronchitis/Pulmonary Function

The inhalation of welding fumes and gases have been shown to cause decrements in pulmonary function and the development of other chronic nonmalignant respiratory diseases. Many studies (Doig and Challen 1964; Hunnicutt et al. 1964; Kujawska 1968; Ulrich et al. 1974; Antti-Poika et al. 1977; Akbarkhanzadeh 1980; Keimig et al. 1983; Sjogren and Ulfvarson 1985; Oleru and Ademiluyi 1987) have reported the potential health risk to welders from exposure to fumes and gases of unknown composition. Other studies (Doig and Challen 1964; Glass et al. 1971) have shown a risk of exposure to phosgene resulting from the decomposition of trichloroethylene that may be present in the welding work environment. Several other studies (Hunnicutt et al. 1964; Fogh et al. 1969; Akbarkhanzadeh 1980; Sjogren and Ulfvarson 1985) have demonstrated an association between smoking by welders and an increased risk of developing respiratory disease. The following studies are representative of those collective data.

Kujawska [1968] reported on a study of workers aged 35 to 45 who had been arc welding for at least 10 years, had never been employed in trades that would have exposed them to fibrosis-producing dusts, and had acquired no respiratory diseases before starting work as welders. Two equal groups of welders were randomly selected (total group size not given) and placed in a group according to radiologic changes in the lung. One group of 30 had radiologic changes indicative of siderosis and the other group of 30 had normal lung radiographs. The welders of both these groups performed about half their work in small and confined spaces (e.g., inside boiler tanks). Covered acid electrodes were used most often; basic and rutile electrodes were occasionally used. No identification of potential exposures was reported. The comparison group (controls) consisted of 30 healthy pipefitters, mechanics, and turners. Each of the 90 workers (welders and controls) was given a physical examination including medical history, X-ray, ECG, and lung function tests such as lung volumes and capacities, pulmonary ventilation, and examination of alveolar ventilation. No significant differences in age, height, weight, or length of service were found between groups. The distribution of smokers and nonsmokers was also similar. Complaints of labored breathing (86%) and dry cough (40%) were more frequent in the group of welders with siderotic changes than in the other group of welders (37% and 3%) or controls (10% and 7%). Chronic bronchitis was found only in the two groups of welders, indicating a statistically significant difference ($p<0.05$) from controls. In addition, reduced pulmonary function parameters (including lower values of the VC and FEV_1 and an increase in the ratio of residual volume to TLC) were found in the group of welders with siderotic changes.

Antti-Poika et al. [1977] found simple chronic bronchitis to be more prevalent ($p<0.01$) among 157 electric arc welders than among 108 controls who were employed at the same facility but not exposed to welding fumes. The controls were matched to welders with respect to age, smoking habits, and social class. The prevalence of simple chronic bronchitis was compared with the length and concentration of exposure, but no dose-response relationships were noted. The welders (average age was 36.1 $\pm$ 10.1 years) mainly used covered electrodes and had been welding for 3 or more years for at least 3 hours a day. Most worked in engineering shops. Samples of total fumes were collected outside the helmet at the time of the study, and concentrations ranged from 1.0 to 9.0 mg/m^3 as an 8-hour TWA. No historical exposure data were reported.

(i) Phosgene Poisoning

Several cases of respiratory distress and pulmonary function impairment have been attributed to phosgene exposure. For example, Doig and Challen [1964] described seven workers who had been complaining for several months about periodic attacks of mild to severe respiratory distress, cough, chest constriction, and breathlessness while they performed gas metal arc welding. The cause of the problem was attributed to vapors from an inadequately ventilated degreasing tank that contained trichloroethylene. The tank was positioned next to open doors so that air currents carried the trichloroethylene vapor 46 m or more to the welding bay, where it decomposed (as a result of heat and ultraviolet radiation from the arc) and formed phosgene.

In another case of phosgene poisoning, a welder experienced chest congestion, difficult breathing, and coughing while welding metal studs to metal links using gas metal arc welding with carbon dioxide [Glass et al. 1971]. The studs were cleaned in an open bucket of trichloroethylene adjacent to the welding bench, and the still-damp studs were placed on the bench and welded. By the end of the morning, the welder's gloves were soaked with trichloroethylene. Examination of the welder 24 hours after exposure revealed reduced vital capacity and FEV_1, airway obstruction, arterial hypoxia, and impaired carbon monoxide transfer. No exposure measurements were reported.

(ii) Interactive Effects of Smoking and Welding

Hunnicutt et al. [1964] reported on one of the first cross-sectional studies that took into account the smoking habits of welders. The study group consisted of 100 electric arc welders and an equal number of nonwelding workers employed at the same plant who were not exposed to welding fumes. The welders were under 60 years of age and had 10 or more years of welding experience in shipyards. Arc welding was the predominant process that was used. However, no exposure data were reported. The following pulmonary tests were conducted on all individuals: FVC, FEV_1, maximum expiratory flow rate (MEFR), maximum mid-expiratory flow rate (MMF), and maximum breathing capacity (MBC). A statistically significant ($p=0.01$) decrement in welders compared to controls was noted for FEV_1, MEFR, and MMF. Seventy-one percent of the welders and 59% of the controls had a history of cigarette smoking. The combined effects of cigarette smoking and exposure to welding fumes increased the likelihood of impaired pulmonary function. Among smokers, the incidence of abnormal pulmonary function in welders was twice that observed in controls. Complaints of shortness of breath, coughs, expectoration, and wheezing occurred twice as often among welders who smoked as among welders who did not smoke. Radiographic evidence of siderosis was found in 34% of the welders (smokers and nonsmokers combined), but the authors found no correlation between degree of respiratory impairment and radiographic abnormality. Siderosis was not observed in the controls.

Fogh et al. [1969] reported on the examination of a group of 154 electric arc welders (more than half [number not given] were shipyard welders while the remaining were engine/boiler welders), 2 oxyacetylene cutters, and 152 nonexposed comparison workers from the same locations. The authors found an increased incidence of chronic bronchitis with increased tobacco smoking in welders as well as in the comparison group when compared to those workers from both groups who did not smoke. Decreased pulmonary function (i.e., FEV_1) was found to be statistically significant among nonsmoking welders when compared with either the welders or controls that smoked (i.e., <10 cigarettes/day, p=<0.05; >10 cigarettes/day, p=<0.01). No statistically significant difference was shown when welders who smoked were compared with the control group of smokers. Among all the controls, symptoms did not increase with age. However, in welders under and over 50 years of age the prevalence of symptoms was 25% and 55%, respectively ($p<0.05$). Among the welders who smoked, 26% of those under the age of 50 and 55% of those over 50 displayed increases in bronchitic symptoms. Neither age group differed significantly when compared to the same age groups of smokers in the comparison group. Chest X-rays revealed a fine mottling indicative of siderosis in five welders (3%). No exposure data were reported.

Barhad et al. [1975] reported on the prevalence of respiratory symptoms and the impairment of ventilatory function in a group of 173 shipyard welders who had 5 or more years of welding experience. The average age was 34.1 years (range: 22 to 57). Cough was found to be increased 22% and chronic bronchitis 20% in welders when compared to a control group of workers from the same shipyard but with no welding fume exposure. The prevalence of chronic bronchitis was 1.5 times more frequent among welders when compared to controls; the difference in prevalence tended to be larger in nonsmokers (12% of welders versus 3% of controls) as compared to smokers (26% of welders versus 21% of controls) but the limited number of observations precluded any statistical analysis. Dyspnea and wheezing ($p<0.001$) and paroxysmal dyspnea ($p<0.005$) were approximately two times more common among welders (smokers, ex-smokers, and nonsmokers) when compared to controls matched for age and smoking habits. The major type of welding was arc with some oxyacetylene torch and shielded welding. At the time of the study, breathing zone welding fume concentrations were found to range from 6 to 36 mg/m^3 while welding in open work areas and 48 to 92 mg/m^3 in confined spaces. Nitrogen oxide exposures averaged 1.7 mg/m^3 for shielded and 1.1 mg/m^3 for arc welding. Carbon monoxide exposures averaged 17 mg/m^3 for torch welding, 8.4 mg/m^3 for electrical, and 6.3 mg/m^3 for flux welding. No historical exposure data were reported.

A similar type of analysis of shipyard welders was performed by Akbarkhanzadeh [1980]. A study was initiated to determine the influence of welding fumes and cigarette smoke on the bronchopulmonary system. The study included 209 welders with 1 or more years of welding experience (mostly shielded metal arc) and a comparison group of 109 shipyard workers who were not exposed to welding fume and who worked for at least 10 years in the same work environment. The welders and the comparison group were divided into smokers, ex-smokers, and nonsmokers. The durations of exposure for welders who smoked (22.5 years) and those who did not smoke (20.9 years) were similar. The smoking habits of the welders and the comparison group were reported to be identical. Persistent cough and phlegm were found to be twice as frequent among welders who smoked (16.7%) as among the comparison workers who smoked (8.3%). Chronic bronchitis was found only in welders (12.4%) who smoked or had smoked. The mean duration of exposure for these welders was 30 years.

For all welders the FEV_1 was less (3.77) than that of the total comparison group (4.03) and less for the nonsmoking welders (3.92) when compared to the controls who did not smoke (4.27). Differences observed for both groups were statistically significant ($p<0.025$). Although the FEV_1 was lower among welders who smoked when compared to controls who smoked (3.63 versus 3.82), the difference was not statistically significant. The FVCs for smoking (4.91) and nonsmoking (5.10) welders were lower than the corresponding smoking/nonsmoking (5.07 and 5.40, respectively) comparison groups. These differences were not statistically significant. With advancing years of exposure, all lung function parameters of welders deteriorated more than those of workers in the comparison group. No exposure data were reported.

A cross-sectional study was reported by Keimig et al. [1983] on the prevalence of respiratory symptoms or impaired lung function in welders exposed to fumes and gases from gas metal arc welding and flux core welding on mild steel. Welders and controls were white males, aged 25 to 49 and were employed for at least 4 years at a plant that manufactured heavy construction equipment. The study group was comprised of 91 welders (46 nonsmokers, 45 smokers) with a mean welding exposure of 108 months, and 80 controls (35 nonsmokers, 45 smokers) who were employed at the same plant but had jobs with minimal exposure to respiratory irritants. Occupational and smoking histories were collected from all subjects. The types of pulmonary function tests given and the questionnaire administered to all subjects were in accordance with the guidelines of the American Thoracic Society. Measurements of pulmonary function were made on each subject before and after each work shift.

As expected, welders and controls that smoked reported a higher frequency of respiratory symptoms (e.g., bronchitis, pneumonia, cough) than corresponding nonsmokers. Although welders who did not smoke reported higher frequencies of symptoms than nonsmoking controls, the differences were statistically significant ($p<0.05$) for only the symptoms of increased phlegm and episodes of cough and phlegm. Pulmonary function measurements were compared both within and between welders and controls, and by smoking status. Predicted normals were not used in the statistical analysis. The only statistically significant differences noted were decreases in forced vital capacity (FVC) measurements at the end of the work shift for nonsmoking welders, nonsmoking controls, and smoking controls. The authors concluded that these differences were not attributable to welding exposure, because controls as well as welders showed a significant decrease. Nonsmoking welders and smoking welders compared to respective controls did not have significantly decreased mean values of FVC or forced expired volume in 1 sec (FEV_1). The mean expiratory flow rates and forced expiratory flow rates measured at 75% of the FVC were found to be lower but not significantly different for welders when compared to controls. Breathing zone air samples collected near welders at the time of the study indicated iron oxide concentrations of 1.3 to 8.5 mg/m^3. No detectable amounts of chromium, copper, fluoride, and lead were found in any of the air samples.

A more detailed cross-sectional study was described by Sjogren and Ulfvarson [1985] who assessed the respiratory symptoms of cough, phlegm, and irritation; chronic bronchitis; and pulmonary function of male welders in Sweden. Welders were identified from the Swedish Register of Enterprises, Bureau of Statistics, and placed into three study groups: those who welded using gas metal or tungsten arc on aluminum (Group 1); those who welded with coated electrodes on stainless steel (Group 2); and those who welded on railroad tracks (Group 3). To be included in the study, each welder must have worked at least 1 year, spending at least 3.5 hours per workday performing the type of work identified above. No specific restrictions on the amount of welding time per day were applied to Group 3. All workers who were asked to be in Groups 1

(64 welders) and 2 (46 welders) agreed to participate. The median exposure time was 5 years (range: 1 to 24) in Group 1 and 15 years (range: 1 to 39) in Group 2. A total of 149 welders who were asked to be in Group 3 agreed to participate. A nonwelding comparison group was chosen for Groups 1 and 2 from the same companies and were matched by age (with a variance of 4 years) and smoking habits. The comparison group for Group 3 included 70 railroad workers who did not weld. This group was not matched for age or smoking habits.

All three groups of welders had higher frequencies of chronic bronchitis than their respective comparisons, but the differences were statistically nonsignificant and appeared to be more dependent on smoking than on welding fumes [Sjogren and Ulfvarson 1985]. However, overall respiratory symptoms were more prevalent for welders working with gas-shielded welding on aluminum (Group 1) than the comparison group, and were statistically significant (p=0.03) with increasing exposure to ozone. Exposure to ozone rather than to aluminum fumes appeared to be responsible for the excess in the observed respiratory symptoms of Group 1 welders [Sjogren and Ulfvarson 1985]. Almost 50% of the exposures to ozone exceeded 0.1 ppm when gas metal arc welding was performed on aluminum. Likewise, welders in Groups 2 and 3 displayed more respiratory symptoms with increasing chromium exposures, but the difference was not statistically significant. More than 80% of the hexavalent chromium exposures exceeded 20 $\mu g/m^3$ when stainless steel was welded with coated electrodes.

According to the authors, respiratory symptoms were not related to total fume concentrations (concentrations not stated) or nitrogen oxides (<5 ppm). No differences were observed regarding FVC or FEV_1 between the three groups of welders and their respective comparison groups.

Oleru and Ademiluyi [1987] reported the results of pulmonary function measurements made on workers engaged in welding and thermal cutting of window and door frames made from medium and high alloy steel and aluminum. A group of 67 (36.8%) from a total of 182 men in the workforce were evaluated for decrements in pulmonary function. Of the 67 subjects, 16 were maintenance workers who were indirectly exposed to welding fumes and gases; 13 were engaged in mild steel welding and 7 were engaged in mild steel cutting; 18 were involved in aluminum cutting operations; and 13 were responsible for the paint dipping of metal frames. A modified British Medical Council respiratory disease questionnaire was administered to all subjects. Lung function assessments including peak expiratory flow rate (PEFR), one second forced expiratory volume (FEV_1), and forced vital capacity (FVC) were made with a Wright's peak flow meter for PEFR and a Vitalograph spirometer for FEV_1 and FVC. To assess the potential acute respiratory effects that may have occurred over a work-week (40 hours) 8 of the 13 mild steel welders were given spirometric tests on Monday morning and after the work shift on Friday. To measure possible pulmonary function changes that may have occurred after an 8-hour work shift and 3 consecutive work shifts, the peak flow test was administered to all 13 welders and 13 paint dippers before and after the work shifts on Wednesday and Friday. The expected lung function parameters of the subjects were calculated from the pulmonary function equations developed for a group of normal, non-industrially exposed Nigerian subjects. Only 9 of the 67 subjects were found to have ever smoked with an average cigarette comsumption of less than 5 per day and an average duration of about 4 years.

Although not statistically significant, those workers classified as maintenance workers had higher lung function measurements (FEV_1 and FVC) than the other groups of workers. However, there was no evidence of obstructive lung disease among any of the groups as supported by the high FEV_1/FVC ratios observed for all subjects, with the lowest 95% confidence interval for any group being 87.6% to 84.2% found for the maintenance workers. Seven cases of restrictive lung impairment were observed among the subjects--3 paint dippers, 2 aluminum workers, and 2 welders. All complained of coughing, chest pains, and difficulty in breathing. The length of employment for these cases ranged from 3 to 7 years. The eight welders who were given spirometric lung function tests to assess the effects of exposure over a work week (40 hours) demonstrated statistically significant ($p<0.05$) decrements in all parameters measured. Peak flow measurements made on this group after an 8-hour work shift showed acute changes in pulmonary function that were statistically significant ($p<0.05$); however, these changes in pulmonary function were not found to be significantly different when welders were tested at the end of three consecutive work shifts. Statistically significant ($p<0.005$) changes in peak flow measurements were observed for the 13 paint dippers when tested after either an 8-hour work shift or 3 consecutive work shifts.

The absence of any obstructive lung disease among the exposed subjects is consistent with the low number of subjects who smoked. The analysis of spirometric and peak flow rate data gathered on a small number of welders and paint dippers after 8-, 24-, and 40-hour work shifts did demonstrate statistically significant changes in lung function. However, because of the low participation rate (36.8%) it is not possible to determine the significance of these data. Although no exposure data were collected, the authors hypothesized that based on the amount of settled dust that had accumulated in the work area, airborne dust concentrations probably exceeded 5 mg/m^3.

(e) Summary--Nonmalignant Pulmonary Diseases

The acute respiratory diseases metal fume fever and pneumonitis have been observed in workers involved in many types of welding processes. Several studies have shown the occurrence of metal fume fever in workers exposed to mixed fume compositions [Ross 1972; Johnson and Kilburn 1983] and to specific metals [Drinker 1922; Drinker et al. 1927]. In all cases, workers experienced nonspecific systemic reactions, including eye and throat irritation, headache, shortness of breath, and nausea that usually ceased within 24 hr after removal from exposure. Likewise, welders' pneumonitis has been documented in several case reports and cross-sectional morbidity studies that have shown exposures to the mixed fume composition [Kleinfeld et al. 1957; Beton et al. 1966; Townshend 1968; Blejer and Caplan 1969; Patwardhan and Finckh 1976; Jindrichova 1976; Herbert et al. 1982] and gases [Molos and Collins 1957; Challen et al. 1958; Maddock 1970; Mangold and Beckett 1971] to be a causative factor in the observed cases of respiratory distress, pulmonary edema, and diminished pulmonary function. Except for limited exposure data reported by Kleinfeld et al. [1957], Molos and Collins [1957], and Challen et al. [1958], all the above studies lacked quantitative exposure data and reported workers being exposed to welding fumes and gases in confined spaces or poorly ventilated work areas. Several fatalities have been observed among workers acutely exposed to cadmium fumes [Beton et al. 1966; Patwardhan and Finckh 1976] and nitrogen dioxide [Maddock 1970].

The occurrence of pneumoconiosis, including siderosis, was first recognized in 1936 among a group of welders [Doig and McLaughlin 1936]. Since then, many case and epidemiologic reports [Britton and Walsh 1940; Sander 1944; Sander 1947; Doig and McLaughlin 1948; Mignolet 1950] have described similar clinical findings of asymptomatic, benign, and radiologically detectable lung changes in welders. Before 1950, much of the welding was performed with bare metal electrodes that produced high concentrations of iron oxide. Since the replacement of bare metal electrodes with covered electrodes, the potential for mixed exposure to other metal fumes has increased. As a result of these mixed exposures, there have been subsequent reports of welders in which the complications of fibrosis [Stettler et al. 1977; Meyer et al. 1967], pulmonary impairment [Meyer et al. 1967; Brun 1972; Levy and Margolis 1974], and reticular nodular shadows [Kleinfeld et al. 1969; Attfield and Ross 1978] were identified with siderosis.

Bronchitis and decrements in pulmonary function have been reported in welders who have been involved in many types of welding processes. Welders employed in shipyards have shown statistically significant decrements in pulmonary function [Hunnicutt et al. 1964; Fogh et al. 1969] and increases in chronic bronchitis [Fogh et al. 1969; Barhad et al. 1975; Akbarkhanzadeh 1980]. With the exception of one study [Barhad et al. 1975], in which exposures to welding fume were measured at 6 to 36 mg/m^3 in welders' breathing zones and 48 to 92 mg/m^3 in confined spaces, no exposure data were reported. The interpretation of these studies is complicated by the heterogeneity of welding exposures and the possible presence of asbestos as a concomitant respiratory hazard. Studies reported by Keimig et. al [1983] and Oleru and Ademiluyi [1987] on welders exposed to mild steel fume and gases in industries other than shipyards observed differences in pulmonary function measurements between welders and nonexposed groups but could not differentiate between smoking and welding exposure on the observed changes. Keimig et al. [1983] found a higher frequency of reported symptoms of phlegm and episodes of cough and phlegm for welders who smoked compared to nonsmoking welders. Decrements in pulmonary function parameters were reported by Oleru and Ademiluyi for welders after an 8-hr work shift and at the end of a 40-hr workweek. Although these differences were statistically significant, there was a low participation rate (36.8%) in the study. Several other studies [Mangold and Beckett 1971; Antti-Poika et al. 1977; ACGIH 1986] have shown a statistically significant increase in chronic bronchitis in welders performing different welding tasks when compared to nonexposed comparison groups. In all the studies where chronic bronchitis occurred, the prevalence of the disease increased with the increasing use of tobacco.

(2) Respiratory Cancer

The following assessment of epidemiologic investigations provides information about the possible association between cancer and occupational exposure to welding fumes and gases [Breslow et al. 1954; Dunn and Weir 1968; Ott et al. 1976; HMSO 1978; Blot et al. 1978; Gottlieb 1980; Sjogren 1980; Milham

1983; Beaumont and Weiss 1981; Polednak 1981; Becker et al. 1985; Newhouse et al. 1985; Steenland et al. 1986; Schoenberg et al. 1987; Sjogren et al. 1987]. Many of the studies report standard mortality ratios (SMRs) greater than 100 or odds ratios (ORs) above 1.0, which suggests an increased risk of respiratory cancer. However, some of these studies are not statistically significant and many do not account for the confounding factors of smoking or possible asbestos exposure. To facilitate discussion, the studies have been grouped as cohort mortality or case-control studies. To permit comparison of study results, summaries of these studies (including information on study design, observed/expected numbers, SMRs, ORs, etc.) are presented in Tables IV-3 and IV-4.

(a) Cohort Mortality Studies

The study reported by Sjogren [1980] of Swedish welders has been the only cohort mortality study to specifically assess the association between lung cancer mortality and exposure from welding on stainless steel. The study cohort included 234 nonasbestos-exposed stainless steel welders who had a minimum of 5 years exposure between 1950 and 1965. The cohort was followed through December 1977. Of the 234 welders, 207 welded with covered electrodes most of the time. An OR of 4.4, based on three lung cancer deaths ($p<0.03$), was observed among the stainless steel welders when compared to Swedish death rates. All three welders who died of lung cancer were cigarette smokers. The OR was still statistically significant at $p<0.05$ after adjusting for a theoretical 10% increase in cigarette smoking among stainless steel welders. No exposure data were available for the study cohort; however, measurements of chromium taken in 1975 at a similar stainless steel welding process revealed median TWA chromium concentrations of 210 $\mu g/m^3$ while welding with covered electrodes and 20 $\mu g/m^3$ during gas-shielded welding. The author stated that only a minor fraction of the exposure was in the hexavalent form; therefore, the concentrations were an overestimate of hexavalent chromium exposure.

In 1987, Sjogren et al. [1987] reported on the follow-up analysis of these 234 stainless steel welders who were exposed to high concentrations of chromium. After 7 years of additional follow-up, the mortality of this cohort was reanalyzed and the results compared to another cohort that consisted of 208 railway track welders exposed to low concentrations of chromium (<10 mg/mg^3). The participants of both cohorts had welded for at least 5 years sometime between 1950 and 1965 and were followed for mortality until December 1984. The expected number of deaths in the two cohorts were calculated by the multiplication of the person-years of observation within 5-year age categories during 1955-1984 by cause-, gender-, age-, and calendar-year-specific national death rates of Sweden. An increase in deaths (SMR=249) from respiratory cancer was observed for the cohort of welders who were exposed to high concentrations of chromium. In contrast, deaths from respiratory cancer in the low-exposure cohort of welders were less than expected (1 death observed, 3 deaths expected). When welders who had high exposures to chromium were compared with those who had low exposures, the number of deaths from respiratory cancer was significantly elevated in the high exposure group, which had a relative risk of 7.01 (95% CI = 1.32-37.3). No other statistically significant increase in deaths from other causes was observed in either cohort. The authors noted that the expected number of deaths from respiratory cancer reported in the earlier analysis by Sjogren [1980] were incorrectly calculated as 0.7 instead of 0.9, resulting in an OR of approximately 3.3 (estimated by NIOSH). No correction for smoking habits was made when either cohort was compared with the expected national death rates. However, smoking as a confounder was not considered to have a significant influence on the comparison of lung cancer risk between the two cohorts of welders.

Becker et al. [1985] reported on a retrospective mortality study of 1,224 welders and 1,694 turners (machinists) who were employed in 25 German factories from 1950-1970 and followed until 1983. The death rates of welders were compared with the death rates from internal and external comparison groups. The internal comparison, based on the death rates of turners not exposed to nickel or chromium, yielded a statistically significant OR of 2.4 for welders ($p<0.05$) for all cancers and a statistically nonsignificant OR of 1.7 for cancer of the trachea, bronchus, and lung. External analyses (German National death rates) showed that the SMRs for all cancers; cancer of the trachea, bronchus, and lung; and respiratory diseases were statistically less than expected ($p<0.05$). Increases in ORs and SMRs for welders who used covered electrodes and who had greater than 20 or 30 years latency were observed for all cancers, including cancer of the trachea, bronchus, and lung, when compared to the internal comparison group. Since the method of age adjustment was not given, it was impossible to determine what bias the difference in age distribution of the internal comparison group may have contributed to the results. No historical exposure data were reported.

A retrospective mortality study of 3,247 welders from Seattle, Washington, was reported by Beaumont and Weiss [1981]. The cohort of welders was selected from local union records of the International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers, and Helpers. The welders had a minimum of 3 years of union membership and had worked between 1950 and 1973. A majority of them had been employed at shipyards or metal fabrication shops. An SMR of 132 (p=0.06) for lung cancer was observed when death rates for U.S. white males were used for comparison. The SMR for lung cancer in welders rose to 174 (p<0.001) when the investigators considered the 39 deaths that occurred 20 or more years after first employment. No historical exposure data were reported, especially data regarding exposure to asbestos in shipyards. Likewise, the potential effect of cigarette smoking on the observed excess in lung cancer was not determined. Internal comparison of welders and nonwelders revealed an excess lung cancer risk that was found to be greater among welders employed 20 or more years following first exposure.

In 1986, Steenland et al. [1986] reported on a reanalysis of the Beaumont and Weiss [1981] study using the Cox and logistic regression analyses to compare lung cancer risk of welders. These analyses were thought to be preferable because they use an internal nonexposed comparison group that is more likely to have lifestyles (e.g., smoking habits) similar to the exposed group. The Cox regression analysis compared welding as either a dichotomous or continuous variable with time-since-first-employment and year-first-employed. The logistic regression was used to analyze the 137 lung cancer deaths (cases) and the remaining 8,542 study subjects (controls). Of the total number of controls, 3110 were welders while the remaining 5,432 were other members (e.g., shipfitters, riggers) of the same union who were frequently employed in the same place as the welders. Men who died of lung cancer were compared to men who did not and an OR for lung cancer was determined for welders versus nonwelders.

When welding was analyzed as a dichotomous variable, a statistically significant interaction was observed with year-first-employed (OR=152, p=0.03). An OR of 1.29 (p=0.03) for lung cancer was observed among welders when welding was considered as a cumulative dose in the logistic analysis. An elevated OR of 1.15 still remained for lung cancer among welders when cumulative dose was analyzed in the Cox regression.

In a mortality analysis of 1,027 shipyard welders employed from 1940 to 1968 in Northeast England, Newhouse et al. [1985] reported elevated SMRs for all cancers (SMR=114), and for lung cancer (SMR=113) after excluding mesothelioma. Accurate dates of employment were not available, so analysis by latency and duration of employment was not made. No smoking histories or information on exposures were cited.

Another mortality study of 2,190 Italian shipyard workers in Genoa, Italy was reported by Puntoni et al. [1979]. The study population consisted of working or retired workers as of January 1, 1960 and followed until December 31, 1975 (duration of employment not given). Age- and sex-specific mortality ORs were calculated for 19 occupational groups including electric and gas welders and compared with two comparison groups: the entire male population of Genoa and the male staff of St. Martin's Hospital in Genoa. Overall, the shipyard workers had statistically significant ORs for total deaths and several specific causes of death including all cancers and cancer of the trachea, bronchus, lung, and larynx when compared to the male population of Genoa, Italy. Gas welders had statistically significant increased ORs for total deaths ($p<0.0005$) and respiratory diseases ($p<0.05$), when compared with the same comparison group. No statistically significant excess in lung cancer was noted for either electric or gas welders.

Although no exposure data were reported, the authors cited exposures to other potential carcinogens (e.g., asbestos, aromatic and halogenated hydrocarbons) in the work environment. The smoking habits of the workers were not assessed nor was the study population age-adjusted. The study consisted of a survivor population, with terminated workers not included in the analysis. The absence of terminated workers probably biased the distribution of deaths because of the many long-term workers.

Polednak [1981] reported on a study of 1,059 white male welders from 3 nuclear facilities in Tennessee. Increases of SMRs were found for lung cancer (SMR=150) and diseases of the respiratory system (SMR=133) that were not statistically significant when compared to U.S. white male death rates. Welders were selected for the cohort if they were hired between 1943 and 1973. SMRs for lung cancer (SMR=175) and respiratory disease (SMR=167) were higher among welders not exposed to nickel oxides than for welders exposed to nickel oxides (SMR=124 for lung cancer, SMR=101 for respiratory disease). Two smoking surveys conducted in 1955 and 1966 showed that cigarette smoking among the group of welders who were not exposed to nickel oxides was 2.5 times more prevalent than the nickel oxide exposed group. About 20% of the welders exposed to nickel oxide smoked cigarettes during the years surveyed. The difference in smoking habits may account for the higher SMRs for lung cancer and respiratory disease among the nonexposed group of welders. In relation to duration of employment in all welders, the lung cancer SMR was elevated for those who worked more than 50 weeks, while the respiratory disease SMRs were higher for those with shorter durations of employment. The fume exposures of welders were causally implicated in the increased risk of respiratory diseases, including pneumoconiosis and bronchitis. At the facility where nickel alloy pipes were welded, time-weighted average (TWA) air concentrations of nickel found in 1975-1977 were all higher than 0.015 mg/m^3 (range of concentrations not given). The sample size of the two subgroups of welders was small, and 8.3% of the study cohort was of unknown vital status at the end of the study period. The nonexposed welders were slightly older than those exposed which may have contributed a negative bias to the SMRs.

In a prospective mortality study reported by Dunn and Weir [1968] a slight, but not statistically significant, excess of lung cancer deaths (OR=1.05) was observed for welders and burners studied over an 8-year period. The study design, which included 13 other occupational groups ascertained from California union records, was based on the information gained from 121,314 mailed questionnaires (85% response rate). Statistical analyses were conducted using age- and smoking-specific death rates, and compared with the death rates of the total union population. No exposure measurements were made and employment records were unavailable. Potential exposures were estimated from the general occupational information that appeared on the questionnaire provided by the respondent.

Milham [1983] reported a statistically significant increase in proportional mortality ratios (PMRs) observed for male welders and flamecutters for several causes of death. The proportional mortality study was based on death certificates collected over a 29-year period (1950-1979) in Washington State.

The statistically significant PMRs are reported in Table IV-5. Occupations were derived from death certificates, which were reported to be inaccurate for as many as 30% of the deaths. The study consisted of a survivor population with deaths of terminated workers not included in the study analysis. Smoking and the potential exposure to asbestos were not accounted for and could have had an effect on the outcome of the study.

In a review of lung cancer rates (by occupation) for Los Angeles County, Menck and Henderson [1976] observed a significantly increased SMR of 137 ($p<0.05$) for welders when compared to the age-, race-, and sex-adjusted Los Angeles County employed population. A total of 2,161 death certificates cited lung cancer as the cause of death in white males, ages 20 to 64, during the periods 1968 to 1970. In addition, 1,777 cases of lung cancer in white males during 1972 and 1973 in Los Angeles County were used. Neither the potential effect of asbestos exposure nor smoking habits were assessed in the study analysis.

Table IV-5.--Statistically significant PMRs[a] for welders and flamecutters[b,c]

Cause of death	Observation period 1950-59	1960-69	1970-79	1950-79
Cancer:				
Respiratory system	--[d]	--	136	126
Trachea, bronchus, lung	--	--	136	135
Kidney	--	--	234	182
Nonmalignancies:				
Diseases of respiratory system	164[e]	137[e]	103	122[e]
Chronic bronchitis	--	382	--	256
Bronchitis with emphysema	--	397	--	259
Other	255[e]	--	--	--
Accidents:				
Fires and explosions	314	--	321	229

[a] Proportional mortality ratio.
[b] Adapted from Milham [1983].
[c] $p<0.01$ unless otherwise noted.
[d] Dash indicates $p>0.05$.
[e] $p<0.05$.

Occupation and type of industry were ascertained from death certificates (which only listed last job held) and medical records. Thus a clear delineation of all jobs held, years of employment, and potential occupational exposures could not be made.

In the report published by Her Majesty's Stationary Office [HMSO 1978] of England and Wales, increased mortality caused by pneumonia, lung cancer, and other and unspecified respiratory cancer was observed for gas and electric welders, cutters, and brazers during the period 1970-72. An overall increase (22%) in deaths was recorded even after adjustment for smoking, age, and social class. This was more than was expected for this occupational group. A statistically significant increase ($p<0.01$) in the PMR for lung cancer mortality was found among smokers and nonsmokers. This risk remained statistically significant with an SMR of 116 ($p<0.01$) when controlled for smoking. The number of lung cancer cases recorded in 1966-1967 and 1968-1969 were noted as "particularly" high. In 1968-1969, seven cancer cases were recorded for other and unspecified respiratory organs, whereas only one was expected. Although no explanation was provided, the authors attributed the excess in lung cancer to an association with asbestos exposure. Possible errors in the analysis could have resulted from differences in the occupational classifications used for the numerator and denominator in determining PMRs. Numerator estimates were based on occupations given in death certificates, whereas the denominator used occupations found in the national census data. Therefore, the rates reflect some bias (unknown direction) in their estimation of risk. Although this type of mortality study (which relies on routinely collected data) is useful for identifying associations between occupation and mortality, it is imprecise for detecting complex relationships between cause of death, exposure, and occupation. No information on the types of exposures were available for analysis. Smoking habits were not assessed but were controlled by using a 22% over-incidence for smoking in the analysis.

Ott et al. [1976] reported on a cohort mortality study of 8,171 male workers employed at a chemical facility. The study population was subdivided into two cohorts; the one cohort consisted of those workers (5,994) hired before 1950 and the other consisted of workers (2,177) hired between January 1950 and March 1954. The vital status of all workers was followed until 1973. Analysis of malignant neoplasms was ascertained for 15 job categories including welders and lead burners. Based on 12 malignant neoplasm deaths, welders and lead burners had an elevated but not statistically significant SMR of 162 when compared to U.S. white male death rates. It was not possible to validate the increase of lung cancer based on two observed lung cancer deaths. Although workers who were potentially exposed to arsenicals or asbestos were eliminated from the study, no further characterization of other potential exposures was provided. A potential misclassification bias could have been introduced because workers were assigned job categories based on their job titles the day they were hired; subsequent job changes were not taken into account.

(b) Case-Control Studies

Gerin et al. [1984] reported on a case-comparison study of hospital cancer patients and their possible occupational exposure to nickel. Lung cancer risk was determined on case ascertainment from 17 hospitals in Montreal, Canada. A statistically significant dose-related OR of 3.3 (95% CI=1.2 to 9.2) was reported for patients who were classified as stainless steel welders "exposed to nickel." Welders identified as having no nickel exposures did not have a statistically significant excess risk. Lung cancer patients identified as nonwelders, but who were exposed to nickel, had a statistically significant OR of 2.9 (95% CI=1.3 to 5.7). The potential for exposure to nickel and chromium were highly correlated, with 78 out of 79 cases exposed to both nickel and chromium. Analyses were controlled for age, smoking history, socioeconomic status, ethnicity, and unknown hospital referral patterns. Occupational exposure to nickel was derived from the patients' responses to a semi-structured questionnaire administered by a team of chemists and industrial hygienists who were unaware of the cancer status. The cases were not controlled for a potential asbestos exposure.

A similar case comparison study was conducted by Breslow et al. [1954] of 518 lung cancer patients from 11 California hospitals during 1949-1952. Of the 518 lung cancer patients, 14 (10 welders and 4 sheet metal workers) were classified as having occupations that exposed them to welding fumes. Although no exposure data were presented, the 14 lung cancer patients were probably exposed to welding fumes associated with the use of arc welding and bare metal electrodes, because this was the primary method of welding prior to 1950. An equal number of patients admitted to the same hospital but whose diagnosis was not cancer or respiratory disease, were used as controls and matched for age, race, and sex. A questionnaire was given to lung cancer patients and the controls to determine occupations, tobacco use, and exposure to toxic materials. The 14 lung cancer patients who were probably exposed to welding fume represented a statistically significant ($p<0.05$) occupational group even after adjustment for cigarette smoking.

Gottlieb [1980] observed a statistically significant OR of 1.19 for white and black males (combined) in a case-control study of lung cancer mortality among all workers employed in the Louisiana petroleum industry between 1960-1975. When the relative risks were determined for welders and were stratified by age at death, only the relative risk for welders under age 60 remained elevated at OR=1.89 (95% CI=0.5 to 7.4), suggesting an occupational etiology. Controls were selected from noncancer deaths and matched to the cases individually by sex, race, year of death, parish of residence, and age at death. A survivor bias may have existed because of death certificate identification of the study population. Smoking habits and the potential for asbestos exposure were not included in the analysis.

In an effort to determine the cause of the high rate of lung cancer among male residents of 11 coastal counties of Georgia, a case control incidence study was conducted by Blot et al. [1978]. Cases were identified from hospital records, and death certificates were obtained for lung cancer patients. Controls were selected from hospital admissions and death certificates, and were matched (two controls for every case) closely by sex, race, age, residence, and vital status. A questionnaire was given to patients and controls (or the next of kin) to determine place, type, and length of employment for any job held for 6 months. Patients who had been employed in a shipyard, had an OR of 1.6 (95% CI=1.1 to 2.3, p=0.006) for lung cancer. The 11 patients who were welders or who were exposed to welding fumes had a crude relative risk of 0.7. Although the relative risk of those employed at shipyards was adjusted for cigarette smoking, asbestos exposure, age, race, and sex, the crude relative risk among welders was not adjusted and, therefore, may not be a reliable estimate of cancer incidence.

In contrast to the study reported by Blot et al. [1978], Schoenberg et al. [1987] found an increased risk of lung cancer among welders employed in shipyards who had no reported asbestos exposure. These results were observed in a case-control study that included 763 white males with histologically confirmed primary cancer of the trachea, bronchus, and lung and 900 general population white male controls. All cases and controls were selected from six geographical areas of New Jersey with risk estimates determined by either job title or industry job title category. The effects of smoking and other potential confounders were examined. A more detailed analyses was conducted for shipbuilding workers and included comparisons of risk by job category and by reported exposure to asbestos. Personal interviews of all cases and controls, or their next of kin, were conducted to collect demographic data, information on personal and environment risk factors, smoking history, and diet.

Of the 42 job title categories examined, 15 were considered to be at high risk, with printing workers, janitors, and cleaners having statistically significant ($p>0.05$) increased smoking-adjusted ORs; 11 had smoking-adjusted ORs of 1.3 or greater, while 4 categories with small numbers of subjects had crude ORs greater than 1.3. Of the 34 industry job title categories examined, 13 were considered to be at high risk. Shipbuilding workers, as well as trucking service warehousing and storage workers, had statistically significant ($p>0.05$) increased smoking-adjusted ORs.

The risk for lung cancer among shipbuilding workers was found primarily among subjects with reported nonincidental asbestos exposure. An increased OR both for latency of less than 30 years (OR of 3.9) and for latency of 30-39 years (OR of 1.7) was observed for these workers. When shipbuilding workers were further analyzed by shipyard job category, welders were observed to have a statistically significant increased OR of 3.8 (95% CI=1.8 to 7.8). Of the 33 cases and 18 controls classified as welders, 16 cases and 7 controls were reported to have been exposed to asbestos. When the remaining 17 cases and 11 controls who had no reported asbestos exposure were analyzed, an increased smoking-adjusted OR of 2.5 (95% CI=1.1 to 5.5) remained.

A case-control study was conducted by Olsen et al. [1984] to assess the elevated laryngeal cancer risk found among white males in Denmark, and to determine if any association existed between these cases and exposure to welding fumes. The study population was composed of 271 incident cases of cancer of the larynx and 971 population controls matched on date of birth, sex, and residence. Patients and controls were interviewed to determine occupations, potential exposures, and tobacco and alcohol usage. Based on the analysis of 271 cancer patients during 1980-1982, workers exposed to welding fumes had a statistically significant increased OR of 6.3 (95% CI=1.8 to 21.6) for cancer of the subglottic area of the larynx. An elevated but not statistically significant OR of 1.3 (95% CI=0.9 to 2.0) was observed for cancer of the larynx. After adjustment for quantified tobacco and alcohol usage, the relative risks persisted. When the study was restricted to 12 stainless steel welders, only the relative risk for subglottic cancer remained elevated with an OR of 6.7 (95% CI=1.0 to 33.3).

(c) Summary--Respiratory Cancer

Several of the epidemiologic studies demonstrated statistically significant increased risks for lung cancer among male welding populations [Breslow et al. 1954; HMSO 1978; Sjogren 1980; Beaumont and Weiss 1981; Milham 1983; Gerin et al. 1984; Steenland et al. 1986; Schoenberg et al. 1987; Sjogren et al. 1987]. Four of these studies showed statistically significant dose-response relationships, one with an increasing observation period and duration of welding exposure [Beaumont and Weiss 1981], two with exposures to nickel and chromium during welding of stainless steel [Sjogren 1980; Gerin et al. 1984; Steenland et al. 1986; Schoenberg et al. 1987; Sjogren et al. 1987], and a case control study [Schoenberg et al. 1987] of shipyard welders that was controlled for smoking and accounted for possible asbestos exposure. In one study [Gerin et al. 1984], the contribution of cigarette smoking habits to lung cancer risks was used as a control, while the other study [Sjogren 1980] used a crude estimate of smoking habits (10% more welders who smoke) as the control. The two other studies [Steenland et al. 1986; Sjogren et al. 1987] reaffirmed the excess risk of lung cancer observed by Beaumont and Weiss [1981] and Sjogren [1980]. Steenland et al. [1986] found an elevated risk of lung cancer among the study cohort reported by Beaumont and Weiss [1981] when they used an internal comparison group that shared similar lifestyles (e.g., smoking) and occupational exposures (e.g., asbestos). Likewise, Sjogren et al. [1987] observed that the risk of lung cancer remained increased when the study group that was used in a previous study [Sjogren 1980] was compared to another group of welders who were exposed to lower concentrations of chromium. The remaining three studies [Breslow et al. 1954; HMSO 1978; Milham 1983] support an association between welding exposures and increased risk of lung cancer. One of these three studies made adjustments for the contribution of cigarette smoking to the proportion of welders with lung cancer [Breslow et al. 1954]. The other two studies [HMSO 1978; Milham 1983], although based on national data sets, are relevant since analyses of these types of data are usually not considered sensitive enough to detect the kinds of complex relationships (exposure and effect) observed unless the disease is rare and the occupational association considerable.

In addition to the above cited studies, a study of welders in the Louisiana petroleum industry also showed a statistically significant lung cancer risk [Gottlieb 1980]. However, when the study group was adjusted for age, the OR was not statistically significant.

Five other mortality studies [Dunn and Weir 1968; Puntoni et al. 1979; Polednak 1981; Becker et al. 1985; Newhouse et al. 1985] found elevated risks for lung cancer among male welders. Two of the five were cohort studies conducted on subgroups of white males who worked as welders at nuclear facilities [Polednak 1981] and at sanitary installations and power plants [Becker et al. 1985]. The larger of the two studies [Becker et al. 1985] indicated an OR of 1.7 for lung cancer that, although based on small numbers, remained increased in those workers with greater than 20 and 30 years employment. The smaller cohort study [Polednak 1981] showed elevated SMRs for the two groups of welders who were exposed and not exposed to nickel oxides. Although the welders not exposed to nickel oxides had a higher SMR, this increase could have been attributed to the higher prevalence rate (2.5 times) of smokers within the group as compared to the exposed group of welders. Two of the mortality studies [Puntoni et al. 1979; Newhouse et al. 1985] were conducted on welders in shipyards. These studies indicated elevated relative risks [Puntoni et al. 1979] and SMRs [Newhouse et al. 1985] for subgroups of welders and other occupational groups potentially exposed to welding fumes and gases. However, neither smoking habits nor the potential for exposure to asbestos were taken into consideration in these two studies. The last of the five mortality studies that showed an elevated risk of dying from lung cancer was a prospective study [Dunn and Weir 1968] that used mortality data collected from questionnaires and union records over a 5-year period. A slightly elevated OR of 1.05 was observed when adjusted for age and smoking and compared with the death rates of the total union population. No employment records were available and any potential exposures had to be derived from the questionnaires.

In a case control study [Blot et al. 1978] conducted to investigate the high rate of lung cancer among male residents of 11 Georgia coastal counties, a statistically significant increased OR of 1.6 was found for shipyard workers. However, when cases were analyzed by occupations within the shipyard, a crude OR of 0.7 was observed for welders.

An unusually high elevated risk of cancer (OR = 6.3) of the subglottic area of the larynx was found among 271 cancer patients of whom 42 had been exposed to welding fumes [Olsen et al. 1984]. The high OR persisted after adjustment for tobacco and alcohol use but was found not to be statistically significant when restricted to twelve stainless steel workers. None of the other epidemiologic studies found an elevated risk of larynx cancer.

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).