2. CANCER IN HUMANS

2.1 Introduction

Welding is a broad term for the process of joining metals through coalescence (AWS, 1997). Welding processes generate fumes which contain particulate matter formed from the condensation of metal liquefied during the welding process (see Section 1.1 for further details). In the occupational literature, welding is often grouped together with flame-cutting, which is a closely related process where oxygen and a fuel gas are used to cut a metal. Welding involves concomitant exposure to ultraviolet (UV) radiation, fumes, particles, and gases.

There is extensive literature on the risks of cancer from either welding jobs or exposure to welding fumes from both cohort and case–control studies, and also partly from studies of routinely collected data. Since the previous *IARC Monographs* evaluation in 1990 (IARC, 1990), the number of published epidemiological studies has increased substantially; a few cohorts have also extended the follow-up period. For this monograph, the Working Group has focused its review on those studies that report risk estimates associated with occupation as a welder or exposure to welding fumes. Studies or risk estimates of occupations which may involve unspecific and infrequent welding (such as pipefitters, plumbers, and solderers), are excluded from this review; the frequency of welding in these occupations is not normally clear, and the groupings are too broad to meaningfully evaluate exposure as a welder. Studies that reported only broad occupational aggregations, combining welding with related occupations, were also excluded as they lack specificity for welding.

Assessments of exposure to welding fumes were generally based on occupation as a welder or welding as a job task, rather than on quantitative estimates of individual exposures. Several cancer types have been investigated; there has been a special focus on cancer of the lung, but also a variety of other sites including cancers of the respiratory tract and urinary bladder, haematopoietic cancers, and ocular melanoma.

The cohort studies of welders typically focus on specific occupational or industrial settings; some include assessment of exposure to welding fumes at baseline, but may lack information on exposure to potential confounders such as tobacco smoking and asbestos. Some studies also lack information on exposures after baseline and have a limited number of cases other than cancer of the lung during further follow-up.

The majority of case–control studies have a simple and indirect exposure assessment, for example by job type, but some include more detailed assessments based on job-exposure matrices (JEMs), job-specific questionnaires, and/or case-by-case expert assessment. As a particular strength, case–control studies often include a lifelong assessment of welding history as well as potential confounders, both occupational and non-occupational.

Welders are exposed to a complex mixture of chemical compounds that vary by the welding method and the type of metal to be welded, for example mild steel (MS) versus stainless steel (SS); the latter involves exposure to nickel (Ni) and chromium (Cr) compounds, recognized lung carcinogens (IARC, 2012a). In evaluating the risk of cancer from welding jobs and exposure to welding fumes, it is important to distinguish between exposures which are normally part of the welding environment and those which occur as co-exposures, typically from other working processes not necessarily related to the welding or from non-welding coworkers (e.g. metal grinders in the nearby working environment). In their working environment, welders may be exposed to compounds other than those directly occurring from the welding process which may be considered as potential confounders. Examples of co-exposures that may contribute to the overall occupational exposures of welders, and therefore the potential risk of cancer, include coatings on the welded metal (e.g. paints, grease, and other compounds) as well as compounds used to prepare metal for welding (e.g. trichloroethylene (TCE) or paint strippers). Welders have also been exposed to asbestos as part of heat-protective equipment (including blankets used to cover the weld, in order to prevent abrupt cooling) and as an insulation material in the welding locality, especially in shipyards where asbestos was extensively used.

Tobacco smoking is considered a major potential confounder for certain tobacco-associated cancers observed in welders. Some studies show a higher prevalence of tobacco use in welders compared with the general population (e.g. Dunn et al., 1960; Office of Population Censuses and Surveys, 1978).

In the absence of information on specific co-exposures in studies of cancer of the lung, crude indirect indications of confounding can be considered, for example, the risk of mesothelioma as an indicator of asbestos exposure.

Overall, the Working Group considered the preceding factors in evaluating and comparing study results; heterogeneity in results may partly reflect such differences. The Working Group noted that the studies should ideally include information on material welded, type of welding process, and co-exposure to asbestos and tobacco smoking. Studies that provided this information were considered the most informative for this evaluation. Additionally, exposure–response data were included when they were available in the published reports.

2.2 Ocular melanoma

See Table 2.1 and Table 2.2

Acute overexposure of the eye to UV radiation is common among electric arc welders, and UV radiation is a confirmed cause of ocular melanoma (IARC, 2012b). Because of the rarity of this cancer and the existence of only relatively small cohorts of welders, the association between welding and ocular melanoma has mostly been investigated via case–control studies. The Working Group identified two independent cohort studies (Table 2.1) that included information on welding exposure from cancer registries in the Nordic countries (Siew et al., 2008; Pukkala et al., 2009) and Canada (MacLeod et al., 2017), and less than ten independent case–control studies on ocular melanoma (Table 2.2). Overall, most studies reported an increased risk of ocular melanoma based on dichotomous exposure variables. The welding exposure is self-reported and crude in most studies, and includes job titles such as welder and/or flame-cutter or sheet metalworker; welding tasks are also included in some studies. Most studies did not distinguish between arc welding, which normally involves exposure to UV radiation, and gas welding without UV radiation [including gas welders may attenuate risk estimates]. Most studies specified that they excluded the rare uveal tract melanoma of the iris.

Table 2.1 Population-based cohort studies on cancer and welding or exposure to welding fumes

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Kromhout et al. (1992) Zutphen, Netherlands Enrolment 1977–1978/follow-up 1977–1985	878 men, 67 lung cancer cases; random sample of men born in 1900–1919 who lived in Zutphen for at least 5 yr. Exposure assessment method: expert judgement; two JEMs: general and population-specific (developed from self-reported exposures)	Lung	Welding fumes				Strengths: comparison of two methods of exposure assessment for welding and soldering fumes Limitations: small numbers
			General JEM:	NR	1.54 (0.37–6.30)	Age, smoking	
			Population-specific JEM	NR	1.93 (1.05–3.55)		
van Loon et al. (1997b) Netherlands Enrolment September 1986/follow-up September 1986–1990	Case–cohort analysis: 524 lung cancer cases, 1630 men in the subcohort; general population cohort of 58 279 men aged 55–69 yr; study restricted to subjects who reported a complete job history Exposure assessment method: expert judgement from a self-administered questionnaire; assessment of probability of exposure to welding fumes, asbestos, paint dusts, and PAHs Cumulative score calculated as the sum of the duration of exposed jobs, weighted by exposure probability	Lung	Ever exposed to welding fumes	NR	0.86 (0.46–1.58)	Age, smoking, other occupational exposures, vitamin C, β-carotene, retinol	General population levels of exposure are probably low Strengths: semi-quantitative assessment of exposure to welding fumes; adjustment for smoking, exposure to asbestos, paints, and PAHs and other potential confounders Limitations: self-administered questionnaire; short follow-up
			Welding fumes: lifetime exposure index in tertiles				
			0	457	1		
			1st tertile (low)	17	0.71 (0.31–1.60)		
			2nd tertile	26	1.49 (0.72–3.07)		
			3rd tertile (high)	20	1.01 (0.49–2.06)		
			Trend test *P* value, 0.75				

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Zeegers et al. (2004) Netherlands Enrolment 1986/follow-up 1986–1993 Nested case–control	Cases: 830 men with microscopically confirmed incident carcinomas of the prostate identified by cancer registries and Dutch National Database of Pathology Reports Controls: 1525 subcohort men randomly sampled from cohort Exposure assessment method: questionnaire; self-administered questionnaires recording occupational history of each job and jobs held for > 5 yr	Prostate	Welder: ever employed	12	1.41 (0.51–3.88)	Age	Strengths: information on diet and lifestyle confounders; multivariate analysis Limitations: exposure misclassification; no information on occupational co-exposures; multiple comparisons; few exposed cases
				12	1.81 (0.62–5.30)	Age, fruit, vegetable, dairy, meat, alcohol, smoking, education, family history of prostate cancer, physical activity	
		Prostate	Longest-held profession: welder	5	1.07 (0.23–4.88)	Age	
				5	1.42 (0.27–7.46)	Age, fruit, vegetable, dairy, meat, alcohol, smoking, family history of prostate cancer, education, physical activity	

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Zeegers et al. (2004) (cont.)		Prostate	Profession at baseline: welder	5 5	0.88 (0.21–3.75) 1.19 (0.25–5.64)	Age Age, fruit, vegetable, dairy, meat, alcohol, smoking, family history of prostate cancer, education, physical activity	
Veglia et al. (2007) Europe (multicentre study, 23 centres, 10 countries) Enrolment 1992–2000/ median follow-up for 6.1 yr	217 055 subjects; 809 lung cancer cases; men and women, mostly aged 35–70 yr at recruitment; restricted to centres with information on occupational history (Denmark, Germany, Greece, Italy, Spain, UK) Exposure assessment method: questionnaire; job titles from questionnaires	Lung	Welder Welding shop	55 72	1.67 (1.20–2.30) 1.55 (1.20–2.10)	BMI, physical activity, education, sex, age, smoking, fruits, vegetable	Strengths: large prospective cohort; detailed information on several possible confounders Limitations: job title analysis; no exposure data

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Siew et al. (2008) Finland Enrolment 1970/follow-up 1971–1995	1.2 million men; 30 137 lung cancer cases; all economically active Finnish men born during 1906–1945 who participated in the 1970 population census Exposure assessment method: expert judgement; FINJEM linked to the longest-held job in 1970 to assess exposure to welding fumes, iron fumes, asbestos, SiO_2, Cr, Ni, Pb, B[*a*]P, and smoking; exposure estimates based on the judgment of ~20 experts at the Finnish Institute of Occupational Health	Lung	Welder and flame cutter, SS > 10%	110	0.95 (0.78–1.15)	Age, calendar year	Overlaps with Pukkala et al. (2009) but includes quantitative analysis and further adjustment for smoking and asbestos Strengths: very large cohort; adjustment for smoking and other occupational exposures (including asbestos) Limitations: cross-sectional information on occupation
			Welder, shipyard	26	1.05 (0.69–1.55)		
			Welder, building	24	1.31 (0.84–1.95)		
			Welder, NEC	102	1.39 (1.14–1.69)		
			Cumulative exposure to welding fumes (mg/m^3-yr)			Smoking, asbestos, SiO_2, SES, age, periods of follow-up	
			None	27 192	1		
			Low (0.1–10)	2591	1.09 (1.05–1.14)		
			Medium (10.1–49.9)	287	1.16 (1.03–1.31)		
			High (≥ 50)	67	1.15 (0.90–1.46)		
		Lung (SCC)	Cumulative exposure to welding fumes (mg/m^3-yr)			Smoking, asbestos, SiO_2, SES, age, periods of follow-up	
			None	9275	1		
			Low (0.1–10)	870	1.07 (0.99–1.15)		
			Medium (10.1–49.9)	110	1.26 (1.04–1.53)		
			High (≥ 50)	29	1.55 (1.08–2.24)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Siew et al. (2008) (cont.)		Lung (small cell/ oat cell)	Cumulative exposure to welding fumes (mg/m^3-yr)			Age, smoking, asbestos, SiO_2, SES, periods of follow-up	
			None	4570	1		
			Low (0.1–10)	479	1.15 (1.04–1.27)		
			Medium (10.1–49.9)	46	1.10 (0.82–1.48)		
			High (≥ 50)	7	0.83 (0.40–1.75)		
		Lung (adenocarcinoma)	Cumulative exposure to welding fumes (mg/m^3-yr)			Smoking, asbestos, SiO_2, SES, age, periods of follow-up	
			None	3379	1		
			Low (0.1–10)	342	1.08 (0.95–1.21)		
			Medium (10.1–49.9)	46	1.42 (1.06–1.91)		
			High (≥ 50)	7	1.14 (0.54–2.40)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Pukkala et al. (2009) Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) Enrolment/ follow-up: Denmark 1971–2003; Finland 1971–2005; Iceland 1982–2004; Norway 1961–2003; Sweden 1961–2005	14.9 million people aged 30–64 yr participating in any computerized population census in 1990 or earlier, still alive and living in the country on January 1 in the year following the census. The date and number of census depend on the country: Denmark 1970; Finland 1970, 1980, 1990; Iceland 1981; Norway 1960, 1970, 1981; Sweden 1960, 1970, 1980, 1990 Exposure assessment method: self-administered questionnaire; information on occupation from the 1st census in which the person participated. Original national occupation codes converted to a common classification with 53 occupational categories. Danish welders are included in the category ‘mechanic workers’. Results for welders (2606 women and 74 857 men) limited to Finland, Iceland, Norway, and Sweden	Lung	Welder			Age, calendar year	Overlaps with Siew et al. (2008). Results differed by country, and risk estimates for ocular melanoma were elevated only in Finland. Results for welders excluded Denmark; 91 mesotheliomas in male welders (SIR, 1.79; 95% CI, 1.44–2.20); no mesothelioma in female welders (0.3 expected). Strengths: very large cohort, long follow-up, risk estimates for rare cancers Limitations: information on occupation at one point in time; no adjustment for smoking and other lifestyle factors (partial data to evaluate confounding)
			Men	1798	1.33 (1.27–1.40)		
			Women	25	1.70 (1.10–2.51)		
		Lung (adeno-carcinoma)	Men	408	1.51 (1.37–1.67)		
			Women	5	0.98 (0.32–2.29)		
		Lung (small cell/ oat cell)	Men	237	1.24 (1.09–1.41)		
			Women	7	2.78 (1.12–5.74)		
		Lung (SCC)	Men	590	1.35 (1.24–1.46)		
			Women	4	1.73 (0.47–4.42)		
		Kidney	Men	533	1.25 (1.14–1.36)		
			Women	7	1.12 (0.45–2.31)		
			Both	540	1.24 (1.14–1.35)		
		Kidney (urinary pelvis/UUT)	Men	56	1.39 (1.05–1.80)		
			Women	0.48	0 (0–7.63)		
		Urinary bladder	Men	822	1.06 (0.99–1.13)		
			Women	4	0.80 (0.22–2.04)		
			Both	826	[1.05 (0.98–1.30)]		
		Eye: melanoma	Men	36	1.07 (0.75–1.48)		
			Women	1	1.25 (0.03–6.99)		
		Prostate	Men	2871	1.01 (0.98–1.05)		
		Leukaemia: ICD-7 (code 204)	Men	294	1.09 (0.97–1.23)		
			Women	5	1.08 (0.35–2.52)		
		NHL (CLL): ICD-7	Men	115	0.98 (0.82–1.18)		
			Women	2	1.29 (0.16–4.68)		
		Leukaemia (AML): ICD-7	Men	89	1.23 (0.99–1.52)		
			Women	2	1.23 (0.15–4.45)		
		Nasal cavity and sinuses	Men	29	1.13 (0.76–1.62)		
			Women	0	0 (0–10.33)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Pukkala et al. (2009) (cont.)		Larynx: ICD-7 (code 161)	Men	146	1.14 (0.97–1.34)		
			Women	2	4.93 (0.60–17.81)		
		Mesothelioma	Men	91	1.79 (1.44–2.20)		
			Women	0	0 (0–12.30)		
		Brain	Men	346	0.99 (0.90–1.11)		
			Women	16	1.39 (0.80–2.26)		
		NHL: ICD-7 (code 200, 202)	Men	341	0.91 (0.82–1.01)		
			Women	9	1.12 (0.51–2.13)		
		HL: ICD-7 (code 201)	Men	59	0.98 (0.74–1.26)		
			Women	2	2.17 (0.26–7.85)		
		MM: ICD-7 (code 203)	Men	160	0.95 (0.82–1.11)		
			Women	1	0.34 (0.01–1.91)		
		Pharynx	Men	93	1.05 (0.85–1.28)		
			Women	1	1.28 (0.03–7.14)		
Neasham et al. (2011) Europe, multicentre (23 centres, 10 countries) Enrolment 1992–2000; mean follow-up 9 yr	218 968 subjects; incident cases of NHL ($n = 707$) and HL ($n = 40$); EPIC cohort; men and women, mostly aged 35–70 yr at recruitment; restricted to centres with information on occupational history (in Denmark, Germany, Greece, Italy, Spain, and the UK) Exposure assessment method: questionnaire; job titles from questionnaires	NHL	Welder	23	0.88 (0.58–1.35)	Education, sex, age, smoking, alcohol, centre	Strengths: large prospective cohort; detailed information on several possible confounders Limitations: job title analysis; no exposure data
			Welding shop	37	1.16 (0.72–1.88)		
		HL	Welder	1	0.55 (0.07–4.13)		
			Welding shop	3	1.02 (0.23–4.48)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Pesch et al. (2013) Europe, multicentre (23 centres, 10 countries) Enrolment 1992–2000 Nested case–control	Cases: 754 incident cases of transitional cell bladder cancer, histopathologically confirmed according to WHO criteria, follow-up of 521 468 EPIC participants Controls: 833 randomly selected from all cohort members alive and free of cancer at diagnosis of the index case (incidence density sampling); matched to the cases by sex, age at time of enrolment (± 3 yr), study centre, and other factors Exposure assessment method: questionnaire; job titles from questionnaires	Urinary bladder: TCC	Welder	43	1.39 (0.85–2.27)	Smoking, region, age	Strengths: large prospective cohort; detailed information on several possible confounders Limitations: job title analysis; no exposure data
			Welding shop	63	1.54 (1.01–2.34)		
Saberi Hosnijeh et al. (2013) Europe, multicentre (23 centres, 10 countries) Enrolment 1992–2000; mean follow-up 11.2 yr	241 465 subjects; 477 incident cases of myeloid and lymphoid leukaemia; men and women mostly aged 35–70 yr at recruitment; restricted to centres with information on occupational history (in Denmark, Germany, Greece, Italy, Spain, and the UK) Exposure assessment method: questionnaire; job titles from questionnaires	Leukaemia (myeloid)	Worked in welding shop or as welder	13	1.14 (0.63–2.05)	Age, sex, smoking, alcohol, country	Strengths: large prospective cohort; detailed information on several possible confounders Limitations: job title analysis; no exposure data
		Leukaemia (lymphoid)	Worked in welding shop or as welder	17	0.99 (0.59–1.65)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
MacLeod et al. (2017) Canada 1991–2011	1 108 410 men (including 12 845 welders and 87 460 occasional welders); linkage of the 1991 Census with the CCR; restricted to individuals aged 25–74 yr with a valid code for occupation on the census form Exposure assessment method: questionnaire; based on occupation self-reported at census; welders = employed as 'welders and soldering machine operators'; occasional welders = employed in other occupations potentially involving welding (from a list defined a priori)	Lung	*All welders by industry*			Age, region, education	The cohort of 942 905 female workers included only 370 welders, with less than 5 cases for the cancer sites of interest, and was not further analysed Strengths: large numbers; internal analyses; risk estimates for histological types of lung cancer; subgroup analyses Limitations: exposure defined by occupation (self-reported) at one point in time; no data on smoking, asbestos, or other co-exposures; adjustment for education and analyses restricted to blue-collar workers may minimize confounding
			Non-welders (ref.)	NR	1		
			All industries	265	1.16 (1.03–1.31)		
			Machine equipment, appliances manufacturing	60	1.21 (0.93–1.56)		
			Construction	45	1.27 (0.96–1.67)		
			Repair of transport vehicles	35	1.41 (1.03–1.94)		
			Transport vehicles manufacturing	10	1.11 (0.58–2.14)		
			Shipbuilding and repair	10	1.65 (0.91–2.98)		
			Other industries	70	0.99 (0.79–1.25)		
			Occasional welders	1625	1.12 (1.07–1.18)		
		Lung (adenocarcinoma)	*All workers*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	75	1.12 (0.89–1.41)		
			Occasional welders	455	1.07 (0.97–1.18)		
		Lung (large cell cancer)	*All workers*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	50	1.01 (0.76–1.34)		
			Occasional welders	310	1.01 (0.90–1.14)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
MacLeod et al. (2017) (cont.)		Lung (small cell/ oat cell)	*All workers*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	45	1.54 (1.15–2.07)		
			Occasional welders	220	1.16 (1.01–1.34)		
		Lung (SCC)	*All workers*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	60	1.19 (0.92–1.54)		
			Occasional welders	430	1.33 (1.20–1.47)		
		Lung	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			All industries	265	1.06 (0.94–1.20)		
			Machine equipment, appliance manufacturing	60	1.13 (0.87–1.46)		
			Construction	45	1.12 (0.84–1.48)		
			Repair of transport vehicles	35	1.28 (0.93–1.76)		
			Transport vehicles manufacturing	10	1.02 (0.53–1.96)		
			Shipbuilding and repair	10	1.45 (0.80–2.63)		
			Other industries	70	0.92 (0.73–1.15)		
			Occasional welders	1625	1.02 (0.96–1.07)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
MacLeod et al. (2017) (cont.)		Lung (adenocarcinoma)	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	75	1.07 (0.84–1.36)		
			Occasional welders	455	1.06 (0.96–1.18)		
		Lung (large cell cancer)	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	50	0.94 (0.70–1.26)		
			Occasional welders	310	0.92 (0.81–1.04)		
		Lung (small cell/ oat cell)	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	45	1.31 (0.96–1.79)		
			Occasional welders	220	1.02 (0.88–1.18)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
MacLeod et al. (2017) (cont.)		Lung (SCC)	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	60	1.04 (0.80–1.35)		
			Occasional welders	430	1.13 (1.02–1.25)		
		Mesothelioma	*All welders*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	15	1.78 (1.01–3.18)		
			Occasional welders	65	1.74 (1.34–2.26)		
		Mesothelioma	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	15	1.54 (0.86–2.78)		
			Occasional welders	65	1.48 (1.13–1.96)		

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
MacLeod et al. (2017) (cont.)		Urinary bladder	*All welders*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	100	1.40 (1.15–1.70)		
			Occasional welders	515	0.99 (0.90–1.08)		
		Urinary bladder	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	100	1.47 (1.21–1.79)		
			Occasional welders	515	1.03 (0.94–1.13)		
		Kidney	*All welders*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	60	1.30 (1.01–1.67)		
			Occasional welders	315	0.96 (0.85–1.08)		
		Kidney	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	60	1.34 (1.04–1.73)		
			Occasional welders	315	0.99 (0.87–1.12)		
		Nasal cavity and sinuses	*All welders*			Age, region, education	
			Non-welders (ref)	NR	1		
			Welders	NR	0 (0–0)		
			Occasional welders	25	1.25 (0.82–1.92)		
		Nasal cavity and sinuses	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	NR	0 (0–0)		
			Occasional welders	25	1.15 (0.73–1.82)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
MacLeod et al. (2017) (cont.)		Eye: melanoma	*All welders*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	5	1.55 (0.64–3.76)		
			Occasional welders	20	0.89 (0.57–1.38)		
		Eye: melanoma	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	5	1.66 (0.68–4.09)		
			Occasional welders	20	0.91 (0.56–1.47)		
		Brain	*All welders*			Age, region, education	
			Non-welders (ref.)	NR	1		
			Welders	35	1.16 (0.83–1.63)		
			Occasional welders	190	1.08 (0.93–1.26)		
		Brain	*Blue-collar welders*			Age, region	
			Non-welders (ref.)	NR	1		
			Welders	35	1.17 (0.83–1.65)		
			Occasional welders	190	1.09 (0.93–1.27)		

Table 2.1 (continued)

Reference, location, enrolment period/follow-up	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Wong et al. (2017) USA Enrolment 2002–2004/follow-up 2002–2009	53 224; 2311 ever welders; current and former heavy smokers (> 30 pack-years, quit within past 15 yr if former smoker) enrolled in the National Lung Screening Trial (NLST) with occupational history information; subjects from 33 centres, randomized into two arms (CT, chest X-ray) Exposure assessment method: questionnaire; job title, work duration, and PPE; ever worked as welders and/or founder defined as held welding job for ≥ 1 yr; information on demographics, medical history, and smoking also ascertained on questionnaire	Lung	*All workers*			BMI, age, sex, race, smoking, family history, study, screening	Cohort analysis and follow-up of subjects enrolled in a randomized control trial (findings for both arms combined) Strengths: sensitivity statistical analyses; information on lung cancer subtypes; large number of cases; information on previous exposure to asbestos Limitations: limited exposure information on welding and co-exposures during welding such as asbestos; short follow-up; not able to assess risk in nonsmokers
			Never welded/ never foundry (ref.)	1824	1		
			Ever welder, never foundry	101	1.12 (0.91–1.37)		
		Lung: incidence (all subtypes)	*Duration ever worked as a welder (yr)*				
			None (ref.)	1824	1		
			≥ 1 to < 3	12	0.80 (0.50–1.25)		
			≥ 3 to < 10	29	1.43 (1.04–1.96)		
			≥ 10 to < 25	27	1.24 (0.89–1.73)		
			≥ 25	30	1.20 (0.87–1.67)		
			Trend test *P* value, 0.039 (ordinal)				
		Lung (SCC): incidence (all subtypes)	*Duration ever worked as a welder (yr)*				
			None (ref)	1824	1		
			≥ 1 to < 3	3	1.4 (0.69–2.84)		
			≥ 3 to < 10	13	1.74 (0.97–3.11)		
			≥ 10 to < 25	4	1.41 (0.75–2.66)		
			≥ 25	11	1.91 (1.13–3.22)		
			Trend test *P* value, 0.003 (ordinal)				
		Lung (adenocarcinoma)	*Duration ever worked as a welder (yr)*				
			None (ref)	593	1		
			≥ 1 to < 3	5	0.97 (0.46–2.05)		
			≥ 3 to < 10	5	1.07 (0.55–2.08)		
			≥ 10 to < 25	8	0.93 (0.46–1.87)		
			≥ 25	10	1.39 (0.80–2.43)		
			Trend test *P* value, 0.418 (ordinal)				

AML, acute myeloid leukaemia; B[*a*]P, benzo[*a*]pyrene; BMI, body mass index; CCR, Canadian Cancer Registry; CI, confidence interval; CLL, chronic lymphocytic leukaemia; Cr, chromium; CT, computerized tomography; EPIC, European Prospective Investigation into Cancer and Nutrition; FINJEM, Finnish job-exposure matrix; HL, Hodgkin lymphoma; ICD, International Classification of Diseases; JEM, job-exposure matrix; MM, multiple myeloma; NEC, not elsewhere classified; NHL, non-Hodgkin lymphoma; Ni, nickel; NR, not reported; PAH, polycyclic aromatic hydrocarbon; Pb, lead; PPE, personal protective equipment; SCC, squamous cell carcinoma; SES, socioeconomic status; SiO_2, silicon dioxide; SIR, standardized incidence ratio; SS, stainless steel; TCC, transitional cell carcinoma; UUT, upper urinary tract; WHO, World Health Organization; yr, year(s)

Table 2.2 Case–control studies on ocular melanoma and welding or exposure to welding fumes

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Tucker et al. (1986) USA 1974–1979	Cases: 497; participation rate, 89% Controls: 501 patients with detached retina not due to tumours matched by race, age, sex, race, date of diagnosis; participation rate, 85% Exposure assessment method: telephone interview with detailed information about medical history, family history, employment, and exposure to environmental agents and sunlight; details from ophthalmologic examination and medical history from records; interview with next-of-kin for 17% of cases and 14% of controls, half of them with spouses	Ever vs never worked as welder	4	10.9 (2.1–56.5)	Age, eye colour, history of cataract	Strengths: large number of cases and controls; high participation rate in both cases and controls Limitations: few exposed cases; no dose–response calculations; no information on other UV exposures

Table 2.2 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Seddon et al. (1990) Massachusetts, USA 1984–1987	Cases: 197 [Series 1 population-based] white patients aged 17–88 yr with clinically or histologically confirmed melanoma of the choroid, ciliary body, or both, identified at local hospital or by mailing to ophthalmologists; diagnosed within previous year Controls: 385 [Series 1 population-based] selected by random digit dialling, matched 2:1 by sex, age, city of residence Exposure assessment method: telephone interview including constitutional factors, ocular, and medical histories, and exposure to environmental factors including natural and artificial sources of UV	Arc welder vs never welder Series 1 Series 2	 18 38	 1.3 (0.5–3.1) 0.9 (0.6–1.5)	Age, sex, eye and skin colour, ancestry, use of sun lamps, eye protection, outside work, florescent lighting, southern residence, years of intense exposure, moles	Series 1: results also reported by Ajani et al. (1992), using the same numbers but with fewer covariates in the logistic regression model Series 2: not population-based, 337 cases and 800 sibling controls 140 of the cases were included in both series Strengths: high participation rates in both cases and controls; some information on exposures to UV radiation Limitations: no dose–response assessment
Siemiatycki (1991) Montreal, Canada 1984–1987	Cases: 16 histologically confirmed incident male cases of uveal melanoma, aged 35–70 yr Controls: 3058; 2525 cancer controls + 533 population controls Exposure assessment method: personal interview and collection of detailed occupational history	Exposed vs not exposed to arc welding fumes	4	8.3 (2.5–27.1)	Age, family income, cigarette index	Total number of eye melanoma cases: 16 (Siemiatycki (1991), table 1); analysis was restricted to French-Canadians and cancer controls used Limitations: no dose–response assessment; no adjustments for UV radiation and sun exposure

Table 2.2 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Lutz et al. (2005) Denmark, France, Germany, Italy, Latvia, Portugal, Spain, Sweden, and UK 1995–1996	Cases: 292 incident cases of uveal melanoma, identified from ophthalmologic departments, hospital records, or cancer registries, aged 35–69 yr Controls: 2062 population controls selected from population registers, electoral rolls, or practitioner; frequency-matched by region, sex, and 5-yr birth cohorts; 1094 cancer controls randomly selected from colon cancer patients Exposure assessment method: questionnaire with face-to-face or telephone interview	Worked as a welder or sheet metal worker for ≥ 6 mo			Country, 5-yr age group	Data from France reported in the analysis of Guénel et al. (2001); analysis by occupation used only population controls Strengths: relatively large study size Limitations: only modest participation rate in controls; no assessment of dose–response association; no information on UV radiation or sun exposure; use of colon cancer patients may be problematic (perhaps at higher risk of this cancer due to lack of sun exposure)
		Men	15	2.18 (1.18–4.04)		
		Women	1	0.75 (0.09–6.33)		
		Men and women	16	1.95 (1.08–3.52)		
Guénel et al. (2001) France: 10 administrative areas (départements) 1995–1996	Cases: 50; 29 men, 21 women; patients with uveal melanoma Controls: 479; 321 men, 158 women selected at random from electoral polls after stratification for age, sex, and area Exposure assessment method: questionnaire; estimates of occupational exposure to solar and artificial UV light were made using a JEM	Ever vs never welder or sheet metal worker			Age	Strengths: high participation rate in cases (100%) and modest in controls (76%) Limitations: relatively small study; no adjustments for UV radiation or sun exposure
		Worked for ≥ 6 mo	7	7.3 (2.6–20.1)		
		≤ 20 yr	4	5.7 (1.6–19.8)		
		> 20 yr	3	11.5 (2.4–55.5)		
		Trend test *P* value, 0.0008				
Monárrez-Espino et al. (2002) Germany 1995–1998	Cases: 118 incident cases of uveal melanoma Controls: 475 controls matched by age, sex, and region of residence Exposure assessment method: telephone interviews, exposure status classified based on job history	Welding, brazing, soldering	13	0.90 (0.43–1.76)	Age, region	Overlaps with Lutz et al. (2005)
		Ever welder	<6	1.3 (0.6–2.5)		

Table 2.2 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Vajdic et al. (2004) Australia 1996–1998	Cases: 246 white Australian residents, aged 18–79 yr, with histopathologically or clinically diagnosed melanoma originating in the choroid, ciliary body Controls: 893 controls matched 3:1 by age, sex, and residence, selected from electoral rolls Exposure assessment method: self-administered questionnaire and telephone interview regarding sun exposure, sun-protective wear, and quantitative exposure to welding equipment and sunlamps	Ever (own welding) vs never	73	1.2 (0.8–1.7)	Age, sex, place of birth, eye colour, ability to tan, squinting as a child, total personal sun exposure at age 10, 20, 30, and 40 yr	Strengths: extensive information collected on exposure including sun exposure, use of personal protective equipment, eye burns during welding; dose–response assessment for welding Limitations: relatively low participation rate in controls
		Duration (yr)				
		0.1–4.0	15	0.8 (0.4–1.4)		
		4.1–22	23	1.2 (0.7–2.2)		
		> 22	35	1.7 (1.0–2.7)		
		Trend test *P* value, 0.07				
		Lifetime exposure (h)				
		0.1–52.0	20	1.1 (0.6–1.9)		
		52.1–858.0	30	1.4 (0.8–2.3)		
		> 858	23	1.1 (0.6–1.9)		
		Trend test *P* value, 0.69				
		Usual exposure (h/d)				
		0.05–0.50	27	1.3 (0.8–2.1)		
		0.51–2.00	30	1.3 (0.8–2.1)		
		> 2.00	16	1.0 (0.5–1.9)		
		Trend test *P* value, 0.74				
		Age at first use (yr)				
		> 20	41	1.2 (0.8–1.9)		
		≤ 20	32	1.2 (0.7–2.0)		
		Trend test *P* value, 0.59				
		Type of welding				
		Arc and oxy	46	1.6 (1.0–2.4)		
		Arc only	21	0.9 (0.5–1.6)		
		Oxy only	5	1.3 (0.5–3.7)		
		Electric/spot only	0	0 (0–2.1)		
		Frequency of goggle or mask use during welding				
		Always/almost always	67	1		
		Half of the time or less	6	1.7 (0.5–5.4)		

Table 2.2 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Vajdic et al. (2004) (cont.)		*Number of eye burns during welding*				
		None	44	1		
		1–2	9	0.4 (0.2–0.9)		
		3–5	6	0.6 (0.2–1.6)		
		> 5	14	1.6 (0.7–3.6)		
		Trend test *P* value, 0.78				
Holly et al. (1996) USA 1978–1987	Cases: 221 male white patients with histologically confirmed uveal melanoma, aged 20–74 yr, residing in 11 states Controls: 447 controls selected by random digit dialling matched 2:1 by age (5-yr age group) and residential area Exposure assessment method: interviewer-administered questionnaire with demographic and phenotypic characteristics, occupational history, exposure to chemicals	Ever vs never welder	40	1.9 (1.2–3.0)	None	Strengths: high participation rate in cases and controls Limitations: no direct assessment of UV radiation or sun exposure
		Ever vs never welder	40	2.2 (1.3–3.5)	Age, naevi, eye colour, tanning or burning, sun exposure	
		Duration (yr)			Age	
		0 (ref.)	181	1		
		≤ 1	6	2.2 (0.7–70)		
		2–10	15	1.80 (0.88–3.60)		
		≥ 11	19	1.9 (1.0–3.6)		

CI, confidence interval; JEM, job-exposure matrix; mo, month; NR, not reported; UV, ultraviolet; vs, versus; yr, year

In a case–control study of ocular melanoma in the USA, Tucker et al. (1986) reported an odds ratio of 10.9 (95% CI, 2.1–56.5) based on 4 cases who ever worked as a welder.

Seddon et al. (1990) conducted a case–control study of ocular melanoma in the USA which included two series of cases with partial overlap; either population or sibling controls were used for the analyses. The magnitude of the odds ratios reported for the association between arc welding and ocular melanoma were weaker than in other studies (described below) and, further, differed in the two series. There was overlap in the reported confidence intervals. One report from Ajani et al. (1992) includes results based on one of the two series of cases and controls already reported by Seddon et al. (1990). [The Working Group noted that this study was limited by the lack of a clear description of the overlap between the two case series.]

A small case–control study of ocular melanoma based in Montreal, Canada, reported an odds ratio (OR) of 8.3 (95% CI, 2.5–27.1; 4 exposed cases), based on an expert assessment of any exposure to arc welding fumes (Siemiatycki, 1991).

Lutz et al. (2005) conducted a multicentre case–control study of rare cancers in nine European countries, which included results for ocular melanoma based on dichotomous variables for men who had worked for 6 months or more as welders/sheet metalworkers. The French and German components of this study were published separately (Guénel et al., 2001; Monárrez-Espino et al., 2002). The French component of this study (Guénel et al., 2001) further presented results by duration of employment as a welder: 20 years or more employment (OR, 5.7; 95% CI, 1.6–19.8); and less than 20 years (OR, 11.5; 95% CI, 2.4–55.5) (*P* for trend, 0.0008). They also report an elevated odds ratio for more than five eye burns not specifically due to welding, but the association disappeared when welding was excluded. There was also a significant exposure–response relationship (*P* for trend, 0.003) for cumulative occupational exposure to artificial UV radiation, which included welding as well as other occupations. Arc welding was assigned the highest intensity level for artificial UV radiation from occupation. Another study including a subset of the German participants reported in the Lutz et al. (2005) paper showed an odds ratio of 1.3 (95% CI, 0.6–2.5; < 6 exposed cases) for ever welders (Monárrez-Espino et al., 2002).

Three studies provided information on the association between duration (years) of welding and risk of ocular melanoma (Holly et al., 1996; Guénel et al., 2001; Vajdic et al., 2004), two of which reported a tendency for increasing risk of ocular melanoma with increasing years of welding exposure (Guénel et al., 2001; Vajdic et al., 2004).

A population-based study from Australia, additionally adjusting for eye colour and sun exposure, observed odds ratios of 0.8 (95% CI, 0.4–1.4), 1.2 (95% CI, 0.7–2.2), and 1.7 (95% CI, 1.0–2.7) respectively, for 0.1–4.0, 4.1–22.0, and more than 22 years of welding performed by the worker. No tendencies for increasing risk by increasing welding hours per day or lifetime welding hours were observed. A subgroup with over five eye burns during welding had an odds ratio of 1.6 (95% CI, 0.7–3.6) compared with welders without eye burns. Compared with wearing goggles always or almost always, wearing goggles or a mask only half the time or less during welding resulted in an odds ratio of 1.7 (95% CI, 0.5–5.4) for 6 exposed cases (Vajdic et al., 2004).

A study from the USA of white men showed an overall increased risk of ocular melanoma for ever versus never welders/welding based on 40 exposed cases, but no trend concerning age-adjusted years of exposure was observed (Holly et al., 1996). [The Working Group noted that only some studies are adjusted for indicators of UV radiation from sunlight (Seddon et al., 1990; Holly et al., 1996; Vajdic et al., 2004), which is the main risk factor for ocular melanoma and thereby a potential confounder; however, there was no evidence that confounding by sunlight explained the results.]

A meta-analysis based on several of the above-mentioned case–control studies (Tucker et al., 1985; Seddon et al., 1990; Ajani et al., 1992; Holly et al., 1996; Guénel et al., 2001; Vajdic et al., 2004), including 1137 cases in total, estimated an overall summary odds ratio of 2.05 (95% CI, 1.20–3.51) (Shah et al., 2005). [The Working Group noted that the meta-analyses included the overlapping cases (*n* = 197) reported by Seddon et al. (1990) and Ajani et al. (1992); this attenuates the overall association because these two studies have odds ratios of 1.3 and 1.0, respectively, which are weaker than the overall pooled result and are counted twice.]

2.3 Mesothelioma

Several studies reported on the association between welding and mesothelioma. These studies are an indicator of exposure to asbestos.

2.3.1 Case–control studies

The association between welding and mesothelioma was investigated in a French population-based case–control study including 371 male cases and 732 male population controls (Rolland et al., 2010). A lifelong occupational history of all occupations with a duration of at least 6 months was obtained in face-to-face interviews; each job period was coded by industrial hygienists who were blinded for case–control status according to standard classifications of occupations and industries. In an ever versus never comparison, the odds ratio for the occupational group welders and flame-cutters was 4.64 (95% CI, 2.04–10.56) based on 19 exposed cases. Thirteen of these were employed in shipbuilding and repair, manufacture of structural metal products, or manufacture of fabricated metal products. [The Working Group noted that the observed risk was probably due to asbestos exposure, as all occupations that appeared to be associated with elevated odds ratios in this study are known to entail asbestos exposure (e.g. manufacture of asbestos products, pipe fitters, and sheet metal and shipyard workers). This is a particular set of welders exposed to high concentrations of asbestos, so the results should not be generalized to the exposure of all welders.]

2.3.2 Cohort studies

Cohort studies investigated mortality or the incidence of cancer in welders and reported risk estimates for mesothelioma or cancer of the pleura. A population-based cohort study pooling data from four Nordic countries observed a standardized incidence ratio (SIR) of 1.79 (95% CI, 1.44–2.20) for cancer of the pleura in male welders based on 91 cases (Pukkala et al., 2009). Another population-based cohort study in Canada observed 15 cases in welders, which corresponded to an adjusted hazard ratio (HR) of 1.54 (95% CI, 0.86–2.78) (MacLeod et al., 2017). In this study, the risk of mesothelioma among welders in construction was 2.5 times greater compared with non-welders. A cancer mortality study among arc welders exposed to fumes containing chromium and nickel resulted in a standardized mortality ratio (SMR) of 11.80 (95% CI, 4.73–24.31) based on 7 cases (Becker, 1999). A historical cohort study of mortality among shipyard workers in Genova, Italy, reported a statistically significant standardized mortality ratio (3.77) of cancer of the pleura in arc welders based on 3 cases, and a non-significant standardized mortality ratio (1.69) in gas welders based on a single case (Puntoni et al., 2001; see Table 2.3). [The Working Group noted that the observed risks of mesothelioma or cancer of the pleura among welders in these cohort studies is probably due to asbestos exposure.]

2.4 Cohort studies

The increased risks of cancer associated with exposure to welding fumes have been studied in industrial (Section 2.4.1) and population-based cohorts (Section 2.4.2). Both types of study have reported cancer mortality or incidence for either exposure to welding fumes or occupation as a welder. Studies of cumulative exposure to welding fumes typically had more detailed exposure information at the individual level compared with studies of occupation as a welder, and were therefore considered to be more informative (from an exposure assessment point of view).

Almost all studies reported on mortality or incidence of cancer of the lung for welders or exposure to welding fumes. Due to the high rates of mortality/low rates of survival from cancer of the lung, mortality studies probably capture most of the cancer of the lung cases; however, it should be noted that diagnosis based on death certificate may not be as accurate as incidence data. When studying the association between welding and cancer of the lung, the major potential confounders are tobacco smoking and exposure to asbestos (especially in shipyards). In the absence of data on asbestos exposure, mesothelioma occurrence can be used as a crude indicator. SS welders are exposed to higher concentrations of the established lung carcinogens hexavalent chromium (Cr(VI)) and nickel compounds compared with MS welders.

Risk estimates for other cancer sites of interest including larynx, sinus/nasal cavity, brain, urinary bladder, kidney and lymphohaematopoietic system are reported in Table 2.1 and Table 2.3.

2.4.1 Industrial cohorts

See Table 2.3

Many of the industrial cohort studies of welders reported only on cancer of the lung; the reasons for not reporting on other cancers include the small population numbers or the limited power of the study groups to evaluate other common cancers. Almost all of the studies reported cancer risks for occupation as a welder, and a few studies reported risks for cumulative exposure to welding fumes. Two studies from the same population reported findings only for exposure to welding fumes (Yiin et al., 2005, 2007), and two studies (of overlapping populations) reported findings for occupation as a welder in addition to exposure to welding fumes (Simonato et al., 1991; Sørensen et al., 2007). Related studies are grouped and discussed together, and the description of cohort studies is divided into: (a) the IARC multicentre cohort and studies of contributing national subcohorts; (b) cohort studies of welders at shipyards; (c) cohort studies of welders in other industries; (d) studies considered to be less informative, due to low specificity for exposure to welding fumes or inadequate reference population; and (e) studies reporting on other cancer sites but not the lung.

(a) The IARC multicentre cohort study

See Table 2.3 and Table 2.4

A large multicentre cohort study of welders was coordinated by the International Agency for Research on Cancer (Simonato et al., 1991). Several national subcohorts were updated after the IARC study, and these analyses (Moulin et al., 1993; Milatou-Smith et al., 1997; Becker, 1999; Sørensen et al., 2007) are also reviewed (see Table 2.4). An analysis of the Finnish subcohort (Tola et al., 1988) was published before the IARC study, but is not reviewed separately because the IARC study captures all the relevant findings from this population. In addition, the Working Group suspected that two studies of Italian shipyard welders may overlap with the IARC Italian subcohort, although this was not explicitly stated in the publications. These studies are discussed in the shipyard section (Section 2.4.1(b)(ii)) since there was no clear documentation about the overlap.

(i) IARC cohort

The IARC multicentre cohort study comprised 11 092 welders employed in 135 companies in eight European countries (Denmark, England, Finland, France, Germany, Italy, Norway, Scotland, and Sweden) (Simonato et al., 1991). The cohort included welders from different types of industries, welding different types of metals, and using different welding processes. A specific matrix for welding fumes was developed, relating 13 combinations of welding process and metals welded to average exposure levels for total welding fumes, total chromium, hexavalent chromium, and nickel (Gérin et al., 1993). Welders were assigned to three mutually exclusive groups according to type of welding: shipyards welders, only MS welders, or ever SS welders. [The Working Group noted that type of welding was based on information collected at baseline. The number of workers in each group was not reported.] The latter category included a group of predominantly SS welders that was also considered separately. National reference rates were used to compute standardized mortality and incidence ratios. Mortality analysis of the total cohort (Simonato et al., 1991) showed elevated SMRs for cancers of the lung (SMR, 1.34; 95% CI, 1.1–1.6), larynx (SMR, 1.48; 95% CI, 0.59–3.04), bladder (SMR, 1.91; 95% CI, 1.07–3.15), and kidney (SMR, 1.39; 95% CI, 0.72–2.43), and for lymphosarcoma (SMR, 1.71; 95% CI, 0.63–3.71) [lymphosarcoma is now referred to as non-Hodgkin lymphoma or NHL]. No clear increase in standardized mortality ratios with time since first employment was found for any of these cancer sites.

The standardized mortality ratios for cancer of the lung were elevated by type of welding: 1.26 (95% CI, 0.88–1.74) for shipyard welders, 1.78 (95% CI, 1.27–2.43) for MS welders, 1.28 (95% CI, 0.91–1.75) for ever SS welders, and 1.23 (95% CI, 0.75–1.90) for predominantly SS welders. Analyses of mortality from cancer of the lung were conducted by duration of employment and time since first exposure (employment as a welder) in the four subgroups. A positive relationship was observed with time since first exposure for MS and SS welders, which was more evident for predominantly SS welders, but there was no clear positive trend with duration of employment. No association between mortality from cancer of the lung and cumulative exposure to total welding fumes was reported, but data were not shown (Simonato et al., 1991). An analysis restricted to the two groups of ever SS welders and predominantly SS welders (potentially exposed to more Cr(VI) and Ni over time), with at least 5 years of employment and 20 years since first exposure, also failed to demonstrate a dose–response relationship.

The results for incidence of cancer at several other sites (buccal cavity and pharynx, oesophagus, stomach, intestine, rectum, larynx, prostate, bladder, leukaemia, and other lymphatic neoplasms) were available for the Nordic subcohorts (68% of the total cohort); elevated standardized incidence ratios were reported for cancers of the lung (SIR, 1.37; 95% CI, 1.11–1.68), prostate (SIR,1.46; 95% CI, 1.02–2.02), bladder (SIR,1.21; 95% CI, 0.76–1.84), and buccal cavity and pharynx (SIR, 1.60; 95% CI, 0.95–2.53), and for leukaemia (SIR, 1.26; 95% CI, 0.63–2.25).

Smoking habits were available for the Finnish and Norwegian components of the cohort and were similar to that of the general population. [The Working Group noted that this suggests that smoking alone is unlikely to explain the excess cases of cancer of the lung. The finding of five deaths from mesothelioma indicates that the study population experienced exposure to asbestos. The five cases were distributed across all subgroups (one shipyard welder, two MS welders, and two SS welders) and across all categories of duration and time since first employment.]

[The Working Group noted that the strengths of the study included the large number of welders and the grouping of welders by welded material

Table 2.3 Industrial cohort studies on cancer and welding or exposure to welding fumes

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Simonato et al. (1991) Europe, multicentre (Denmark, England, Finland, France, Germany, Italy, Norway, Scotland, Sweden) Enrolment and follow-up different between countries Cohort	11 092 welders (164 077 person-yr); workers employed as shipyard, MS, or SS welders by 135 companies; different inclusion criteria for each national cohort Exposure assessment method: expert judgement; welding process exposure matrix developed to estimate exposure levels for total welding fumes, total Cr, Cr(VI), and Ni (described in Gérin et al. (1993))	Lung	*Incidence*			Age, calendar period	Type of welding: shipyards, MS only, ever SS, predominantly SS SIR data are only from cohort subjects of Denmark, Finland, Norway, and Sweden
			Welders	92	1.37 (1.11–1.68)		
		Lung	Years since first exposure				
			0–9	14	1.65 (0.90–2.77)		
			10–19	27	1.22 (0.81–1.78)		
			20–29	41	1.42 (1.02–1.93)		
			≥ 30	34	1.24 (0.86–1.73)		
			Total	116	1.34 (1.10–1.60)		
		Lung	Years since first exposure: shipyard welders				
			0–9	5	5.08 (1.65–11.85)		
			10–19	6	1.41 (0.52–3.06)		
			20–29	17	1.61 (0.94–2.57)		
			≥ 30	8	0.63 (0.27–1.23)		
			Total	36	1.26 (0.88–1.74)		
		Lung	Years since first exposure: MS welders				
			0–9	4	1.35 (0.37–3.45)		
			10–19	11	1.62 (0.81–2.90)		
			20–29	11	1.86 (0.93–3.33)		
			≥ 30	14	2.07 (1.13–3.48)		
			Total	40	1.78 (1.27–2.43)		
		Lung	Years since first exposure: SS ever welders				
			0–9	5	1.04 (0.34–2.43)		
			10–19	12	1.07 (0.55–1.86)		
			20–29	13	1.32 (0.70–2.26)		
			≥ 30	9	1.94 (0.89–3.69)		
			Total	39	1.28 (0.91–1.75)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Simonato et al. (1991) (cont.)		Lung	Years since first exposure: predominantly SS welders				
			0–9	2	0.64 (0.08–2.32)		
			10–19	5	0.88 (0.29–2.06)		
			20–29	7	1.26 (0.51–2.60)		
			≥ 30	6	3.12 (1.15–6.79)		
			Total	20	1.23 (0.75–1.90)		
		Lung	Cumulative exposure (mg/m³-yr): predominantly SS welders				
			Cr(VI) < 0.5	3	1.91 (0.39–5.58)		
			Cr(VI) ≥ 0.5	9	1.67 (0.77–3.18)		
			Ni < 0.5	8	2.34 (1.01–4.61)		
			Ni ≥ 0.5	4	1.13 (0.31–2.90)		
		Lung	Cumulative exposure (mg/m³-yr): SS ever welders				
			Cr(VI)< 0.5	7	1.23 (0.50–2.54)		
			Cr(VI) ≥ 0.5	14	1.70 (0.93–2.86)		
			Ni < 0.5	17	1.66 (0.97–2.66)		
			Ni ≥ 0.5	4	1.09 (0.30–2.79)		
		Urinary bladder	*Incidence*				
			Welders	22	1.21 (0.76–1.84)		
		Urinary bladder	Years since first exposure				
			0–9	2	2.19 (0.27–7.92)		
			10–19	3	1.36 (0.28–3.97)		
			20–29	4	1.66 (0.45–4.24)		
			≥ 30	6	2.59 (0.95–5.64)		
			Total	15	1.91 (1.07–3.15)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Simonato et al. (1991) (cont.)		Larynx: ICD-8 (code 161)	Welders	7	1.48 (0.59–3.04)		
		Larynx	Years since first exposure				
			0–9	0	0 (0–6.83)		
			10–19	3	2.09 (0.43–6.12)		
			20–29	4	2.41 (0.66–6.17)		
			≥ 30	0	0 (0–3.32)		
			Total	7	1.48 (0.59–3.04)		
		Oral/ pharyngeal combined	*Incidence*				
			Welders	18	1.60 (0.95–2.53)		
		Nasal cavity and sinuses	Welders	0	0 (0–4.44)		
		Prostate	*Incidence*				
			Welders	36	1.46 (1.02–2.02)		
		Prostate	Welders	10	0.77 (0.37–1.42)		
		Kidney	Welders	12	1.39 (0.72–2.43)		
		Kidney	Years since first exposure				
			0–9	1	0.97 (0.02–5.43)		
			10–19	1	0.43 (0.01–2.41)		
			20–29	7	2.44 (0.98–5.03)		
			≥ 30	3	1.24 (0.26–3.63)		
			Total	12	1.39 (0.72–2.43)		
		NHL: ICD-8 (code 200)	Welders	6	1.71 (0.63–3.71)		
			Years since first exposure				
			0–9	1	1.54 (0.04–8.56)		
			10–19	1	1.06 (0.03–5.91)		
			20–29	1	0.94 (0.02–5.24)		
			≥ 30	3	3.53 (0.73–10.33)		
			Total	6	1.71 (0.63–3.71)		
		HL: ICD-8 (code 201)	Welders	2	0.60 (0.07–2.18)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Simonato et al. (1991) (cont.)		Leukaemia: ICD-8 (code 204–207)	Welders	6	0.63 (0.23–1.38)		
		Leukaemia: ICD-7 (code 204)	*Incidence*				
			Welders	11	1.26 (0.63–2.25)		
		Lymphatic neoplasms ICD-8 (code 202–203)	Welders	7	1.14 (0.46–2.36)		
		Other lymphatic ICD-7 (code 200–203 205)	Welders	15	1.12 (0.63–1.85)		

Table 2.3 (continued)

Reference, location, enrolment period/follow-up, study design	Population size, description, exposure assessment method	Organ site/cancer type	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Moulin et al. (1993) France Enrolment 1975–1976/follow-up 1975–1976 to 1987–1988 (depending on the factory) Cohort	2721 welders, 6683 controls; all male workers employed as welders at the beginning of the follow-up in 13 factories; internal comparison group: 6684 manual workers (excluding boilermakers, foundry workers, painters, or cutters) randomly selected among non-welders in the same factories; restricted to workers employed for at least 1 yr Exposure assessment method: records of welding processes, types of metal, and percentage of working time available at the individual level in eight factories and at the workshop level in five factories; smoking habits from medical records (recorded by the occupational physician once a year); information on asbestos available on factory level only so not relevant for the statistical analysis (it only accounted by separating shipyard from non-shipyard welders)	Lung	Welders vs controls (internal ref.)	NR	1.29	Age	Partial overlap with the IARC study, Simonato et al. (1991) No death from pleural cancer among welders; 3 deaths from pleural cancer among controls, 1.25 expected (SMR, 2.40; 95% CI, 0.49–7.01) Strengths: internal comparison group; smoking habits available for 87% of the cohort Limitations: no data on asbestos exposure
		Lung	Welders	19	1.24 (0.75–1.94)	Age, calendar time, sex	
		Lung	Welders: time since first employment (yr)				
			< 10	1	[0.75 (0.03–3.70)]		
			10–19	3	[0.90 (0.23–2.45)]		
			≥ 20	15	[1.41 (0.82–2.27)]		
		Lung	Welders: duration of employment (yr)				
			< 10	1	[1.19 (0.06–5.86)]		
			10–19	2	[0.63 (0.10–2.08)]		
			≥ 20	16	[1.41 (0.83–2.24)]		
		Lung	Duration of exposure (5-yr lag period)				
			Total welders	19	1.24 (0.75–1.94)		
			Shipyard welders	3	0.91 (0.19–2.67)		
			MS welders only	9	1.59 (0.73–3.02)		
			Ever SS welders	3	0.92 (0.19–2.69)		
			Predominantly Cr(VI)[a]	2	1.03 (0.12–3.71)		
		Larynx	Welders	3	0.67 (0.14–1.97)		
		Pleura	Welders	0	0 (0–8.82)		
		Brain	Welders	0	0 (0–2.75)		
		Leukaemia: ICD-8 (code 204–208)	Welders	2	1.13 (0.14–4.10)		
		HL: ICD-8 (code 200–203)	Welders	2	1.02 (0.12–3.68)		
		Urinary bladder	Welders	1	0.65 (0.02–3.64)		
		Prostate	Welders	0	0 (0–2.09)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Milatou-Smith et al. (1997) Sweden Enrolment 1950–1965/follow-up 1955–1992 Cohort	233 welders (high exposure cohort); 208 welders (low exposure cohort); two cohorts of welders, employed for at least 5 yr during 1950–1965: one of SS welders exposed to high levels of Cr(VI), and one of railway track welders exposed to low levels of Cr(VI) Exposure assessment method: records of information on average levels of exposure to Cr from Swedish measurements in 1975 (SS welders 110 µg/m³, railway track welders 10 µg/m³); no or minimal asbestos exposure (company statements)	Lung	Exposed to high levels of Cr: SS welders			Age, sex, cause, calendar year	Partial overlap with the IARC study, Simonato et al. (1991) Strengths: probably very low asbestos exposure; comparison between the two groups of welders unlikely to be affected by confounding due to smoking Limitations: small cohorts; no information on individual exposure levels; no actual measurements of asbestos exposure; no data on smoking
			Welders	6	1.64 (0.60–3.58)		
		Lung	Exposed to low levels of Cr: MS welders				
			Welders	2	0.41 (0.05–1.48)		
		Lung	Exposed to high vs low levels of Cr			Age	
			Welders	NR	3.98 (0.84–18.80)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Becker (1999) Germany Enrolment 1950–1970/follow-up 1950–1995 Cohort	1213 SS welders, 1688 turners (internal reference group); arc welders exposed to Cr and Ni and turners employed for at least 6 mo during 1950–1970 at 25 factories of the metal-processing industry Exposure assessment method: exposure duration from companies records; assessment of welding exposure characteristics (welding procedure, percentage of working time) and smoking habits at the individual level by interview of the foremen and superiors; average duration of exposure of the welders was 18.3 yr		*Mortality*			Calendar period	Partial overlap with the IARC study, Simonato et al. (1991); strong excess of deaths from mesothelioma; confounding by asbestos likely to explain the lung cancer excess Strengths: internal comparison group; analyses by subgroups Limitations: no data on asbestos exposure
		Lung [includes bronchus and trachea]	Welders	28	1.21 (0.80–1.75)		
		Pleura	Welders	7	11.80 (4.73–24.30)		
		Urinary bladder	Welders	5	2.08 (0.67–4.84)		
		Other lymphatic and haematopoietic	Welders	0	–		
		MM	Welders	1	1.23 (0.03–6.86)		
		Leukaemia (lymphoid): ICD-9 (code 204)	Welders	1	1.52 (0.04–8.51)		
		Leukaemia (myeloid): ICD-9 (code 205)	Welders	0	–		
			Internal analysis				
		Lung	Welders	28	1.30 (0.80–2.12)	Age, calendar period	
		Lymphatic and haematopoietic	Welders	2	0.38 (0.08–1.75)		
		Lung	Duration of exposure (yr)			Calendar period	
			0 to < 10	6	0.99 (0.36–2.15)		
			10 to < 20	11	1.57 (0.78–2.81)		
			20 to < 30	8	1.18 (0.51–2.34)		
			≥ 30	3	1.10 (0.22–3.23)		
		Lung	Time since first exposure (yr)				
			0 to < 10	0	–		
			10 to < 20	2	0.56 (0.06–2.03)		
			20 to < 30	13	1.48 (0.78–2.53)		
			≥ 30	13	1.39 (0.74–2.38)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Becker (1999) (cont.)		Lung	Coated electrodes	11	1.21 (0.60–2.17)		
			Coated electrodes or MIG-MAG/WIG	14	1.40 (0.76–2.36)		
			Exclusively MIG-MAG/WIG, for malignant neoplasms	3	0.88 (0.18–2.58)		
		Urinary bladder	Coated electrodes	3	2.80 (0.57–8.19)		
			Coated electrodes or MIG-MAG/WIG	2	2.12 (0.25–7.66)		
			Exclusively MIG-MAG/WIG, for malignant neoplasms	0	–		
		Brain	Coated electrodes	4	6.18 (1.88–15.85)		
			Coated electrodes or MIG-MAG/WIG	0	–		
			Exclusively MIG-MAG/WIG, for malignant neoplasms	0	–		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Becker (1999) (cont.)		Lymphatic and haematopoietic ICD-9 (code 200–208)	Coated electrodes	1	0.46 (0.01–2.60)		
			Coated electrodes or MIG-MAG/WIG	1	0.39 (0.01–2.19)		
			Exclusively MIG-MAG/WIG, for malignant neoplasms	0	–		
			Effective welding periods per day (%)				
		Lung	≤ 25	15	1.24 (0.69–2.04)		
			> 25	13	1.18 (0.63–2.02)		
		Urinary bladder	≤ 25	2	1.54 (0.18–5.56)		
			> 25	3	2.71 (0.55–7.92)		
		Lymphatic and haematopoietic	≤ 25	0	–		
			> 25	0	–		
		MM and immuno-proliferative neoplasm	≤ 25	0	–		
			> 25	1	2.59 (0.06–14.46)		
		Leukaemia (lymphoid): ICD-9 (code 204)	≤ 25	1	2.86 (0.07–15.94)		
			> 25	0	–		
		Leukaemia (myeloid): ICD-9 (code 205)	≤ 25	0	–		
			> 25	0	–		
			Mortality				
		Larynx	Welders	1	0.73 (0.02–4.09)		
		Kidney and other urinary organs	Welders	0	–		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Becker (1999) (cont.)		Prostate	Welders	3	0.67 (0.14–1.95)		
		Lymphatic and haematopoietic	Welders	2	0.35 (0.04–1.26)		
		HL: ICD-9 (code 201)	Welders	0	–		
		Brain and parts of nervous system	Welders	4	2.02 (0.55–5.19)		
Sørensen et al. (2007) Denmark Enrolment 1964–1984/follow-up 1968–2003 Cohort	4539 welders; male production workers, employed for at least 1 yr at 74 SS or MS companies (shipyards, apprentices, and craftsman excluded), alive at 1 April 1968, born before 1965, who answered the questionnaire in 1986; study population restricted to ever welders who started in 1960 or later Exposure assessment method: welding exposure matrix (based on > 1000 measurements) for welding fume particulates combined with questionnaire data on welding characteristics; questionnaire for asbestos exposure and smoking; next-of-kin questionnaire for the subgroup of deceased	Lung	MS (never SS)	43	1	Age, smoking, asbestos	Partial overlap with the IARC study, Simonato et al. (1991), and Hansen et al. (1996) Strengths: long follow-up; semi-quantitative exposure assessment; adjustment for smoking and asbestos exposure Limitations: self-reported data on asbestos exposure
			SS	32	0.86 (0.52–1.42)		
		Lung	Ever welding	75	1.35 (1.06–1.70)	Age, calendar time, sex	
			Ever SS	34	1.15 (0.78–1.60)		
			Ever MMA-SS	25	1.46 (0.95–2.16)		
			Never MMA-SS	9	0.72 (0.35–1.36)		
			Ever MS, never SS	41	1.59 (1.14–2.16)		
		Lung	All welders: duration of welding (yr)			Age, smoking, asbestos	
			0–5	20	1		
			6–15	27	1.47 (0.73–2.92)		
			≥ 16	28	1.29 (0.65–2.57)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Sørensen et al. (2007) (cont.)		Lung	MS (never SS) welder: duration of welding (yr)				
			0–5	16	1		
			6–15	19	1.19 (0.75–3.80)		
			≥ 16	8	0.83 (0.30–2.26)		
		Lung	SS welders: duration of welding (yr)				
			0–5	13	1		
			6–10	1	0.17 (0.02–1.28)		
			≥ 11	18	1.07 (0.50–2.28)		
		Lung	All welders: cumulative exposure estimate (mg/m^3 × yr)				
			0–15	13	1		
			16–60	34	2.05 (1.02–4.09)		
			≥ 61	23	1.78 (0.84–3.66)		
		Lung	MS (never SS) welders: cumulative exposure estimate (mg/m^3-yr)				
			0–10	4	1		
			11–50	26	3.29 (0.97–11.10)		
			≥ 51	8	1.79 (0.46–6.99)		
		Lung	SS welders: cumulative exposure estimate (mg/m^3-yr)				
			0–5	11	1		
			6–10	6	1.18 (0.40–3.51)		
			≥ 11	15	2.34 (1.03–5.28)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Merlo et al. (1989) Genova, Italy Enrolment 1930–1980/follow-up 1960–1981 Cohort	527 welders: 274 oxyacetylene (MS); 253 electric arc welders (SS); all male shipyard workers employed for at least 6 mo as a welder; electric arc slowly replaced oxyacetylene welding over time (1940s: 66% oxyacetylene; 34% electric arc; 1986: 44% oxyacetylene; 56% electric arc). Exposure assessment method: records of job title (electric arc workers: open spaces, lower levels of gases and fumes; oxyacetylene workers: inside oil tankers, higher levels of gases and fumes); air samples during cutting in oil tankers: B[*a*]P (3–22 μg/m^3), NO_x (3–8.5 ppm), dust (9–27 mg/m^3); higher Ni and Cr(VI) found in SS and MIG welding; asbestos fibres not detected	Respiratory tract	Shipyard welders: external analysis			Age, calendar period	One death from asbestosis among electric arc workers; no information on mesothelioma Strengths: indirect adjustment for smoking based on survey data Limitations: small numbers of exposed cases in subcohorts; follow-up did not start until 30 yr after first date of enrolment (may have missed cases)
			All	16	1.67 (0.95–2.71)		
			Oxyacetylene	12	2.34 (1.21–4.09)		
			Electric Arc	4	0.88 (0.24–2.30)		
		Respiratory tract	Shipyard welders: internal analysis				
			Electric arc welders (ref.)	NR	0		
			Welding	16	2.45 (0.77–7.83)		
		Larynx	Shipyard welders: external analysis				
			All	0	0 (0–2.67)		
			Oxyacetylene	0	0 (0–4.92)		
			Electric arc	0	0 (0–5.83)		
		Bladder and kidney	Shipyard welders: external analysis				
			All	5	2.11 (0.68–4.92)		
			Oxyacetylene	5	3.70 (1.19–8.64)		
			Electric arc	0	0 (0–3.60)		
		Lymphatic and haematopoietic	Shipyard welders: external analysis				
			All	2	0.98 (0.11–3.54)		
			Oxyacetylene	1	0.93 (0.01–5.19)		
			Electric arc	1	1.03 (0.01–5.74)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Puntoni et al. (2001) Italy Enrolment 1960–1980/follow-up 1960–1995 Cohort	3984 male shipyard workers (267 electric arc welders and 228 gas welders); male shipyard workers (whole cohort) employed at the harbour of Genoa Exposure assessment method: records of individual data on job titles from the personnel department; coding the most prevalent job for individuals with different job titles	Lung	Electric arc	19	[1.64 (1.07–2.51)]		Three deaths from pleural cancer among arc welders (SMR, 3.8; NS); 1 death from pleural cancer in gas welders (SMR, 1.7; NS) Limitations: only job titles; confounding by asbestos
			Gas	14	[1.57 (0.89–2.57)]		
		Pleura	Electric arc	3	[3.77 (0.96–10.26)]		
			Gas	1	[1.69 (0.08–8.33)]		
		Larynx	Electric arc	1	[0.82 (0.04–4.04)]		
			Gas	2	[2.00 (0.33–6.60)]		
		Urinary bladder	Electric arc	5	[2.74 (1.00–6.07)]		
			Gas	1	[0.70 (0.03–3.45)]		
		Kidney	All	5	3.82 (1.24–8.91)		
			Electric arc	3	4.00 (0.82–11.69)		
			Gas	2	3.57 (0.43–12.90)		
Newhouse et al. (1985) NE England Enrolment 1940–1968/follow-up 1940–1986 Cohort	3489 workers (welders, caulkers, electricians, and platters; identified from personnel records) at a shipyard; 1027 welders Exposure assessment method: 1960 measurements of iron oxide in mg/m^3 (total general air: 6.3; personal: 13.6); confined spaces without ventilation (general air: 23.6; personal: 31.9); caulkers also exposed to fumes similar in magnitude and composition to welding fumes; asbestos used throughout shipyard but no specific information	Lung	Welders	26	1.13 (0.80–1.57)	Age, calendar year	15% of workforce had died; 1 mesothelioma among welders and 1 among caulkers Strengths: exposure monitoring data available Limitations: limited exposure information; no information on smoking; incomplete employment records did not allow for assessment of employment duration; workers moved between shipyards
			Caulkers	12	2.32 (1.33–3.74)		
		All cancers combined	Welders	49	1.03 (0.79–1.27)		
			Caulkers	18	1.68 (1.09–2.49)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Melkild et al. (1989) Norway Enrolment: 1946–1977/follow-up: 1953–1986 Cohort	4778 male shipyard workers (783 MS workers); male workers first employed at shipyard on southwest coast of Norway for at least 3 mo during the enrolment period; MMA-MS welding predominant until 1970; SS welding did not become common until the mid-1970s; gas-shielded welding introduced in the 1960s Exposure assessment method: questionnaire and company records, classifying job titles within 10 categories; 1973 survey: total fumes 7.3 mg/m^3 (3.6–23.6); Ni: 0.34 mg/m^3 (0.11–1.97); Cr: 0.12 mg/m^3 (0.03–0.65); personal protection equipment and ventilation provided to shops in early 1970s; asbestos used until early 1970s	Lung	Welders	7	2.21 (0.88–4.54)	Age, calendar period	Workers may have contributed to a cancer site in more than one occupational category; may have missed cases occurring during 1947–1952; 2 mesotheliomas observed among non-welders Strengths: description of the type of welding over time and some exposure monitoring data Limitations: limited exposure assessment, which was based on personnel register; no information on smoking in the cohort; exposure to asbestos possible, small numbers of exposed cases
		Lung	Employment duration (yr)				
			< 1	0	–		
			1–5	5	[5.56 (2.04–12.31)]		
			> 5	1	[0.59 (0.03–2.90)]		
		Urinary bladder	Welders	2	[1.33 (0.22–4.41)]		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Danielsen et al. (1993) Norway Enrolment 1940–1979/follow-up 1953–1990 Cohort	4571 male shipyard workers (623 MS welders); identified by personnel register with information regarding name, start, and end dates; mainly MMA welding performed on MS Exposure assessment method: records of interviews with retired workers; high-exposure welders were defined as welders employed ≥ 3 yr and identified as a welder by veteran workers; very high exposure was defined as a subgroup employed ≥ 5 yr as a welder and followed up from the 5th year of employment Environmental monitoring data: total dust 2.5 mg/m^3 (0.8–9.5 mg/m^3)	Lung	Welders	9	2.50 (1.14–4.75)		Smoking differences were estimated to explain a SIR of ~1.25; Cr and Ni levels were low and no mesotheliomas were observed among welders; may have missed cases occurring during 1940–1953 Strengths: high and very high exposure subgroups; internal reference group of shipyard production workers who were not welders or burners Limitations: no quantitative exposure (or semiquantitative exposure assessment); a small number of exposed lung cases among welders; limited information on smoking habits
		Lung	Duration of employment and lag time (yr)				
			≤ 5; no lag	NR	1.7 (0.5–5.5)		
			> 5; no lag	NR	3.0 (1.3–6.9)		
			≤ 5; 10 yr lag	NR	1.8 (0.5–5.7)		
			> 5; 10 yr lag	NR	3.2 (1.3–8.1)		
		Lung	15-yr lag: external analysis				
			All	8	3.08 (1.35–6.08)		
			High exposure	6	3.75 (1.38–8.19)		
			Very high exposure	4	4.00 (1.10–10.20)		
			Shipyard excluding welders and burners	38	1.35 (0.96–1.86)		
		Lung	Employment duration (yr): external analysis				
			≤ 4	3	[2.14 (0.55–5.83)]		
			5–9	0	–		
			≥ 10	6	[3.75 (1.52–7.80)]		
		Urinary bladder	Welders	1	0.59 (0–3.29)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Danielsen et al. (2000) Norway Enrolment 1945–1980/follow-up 1953–1995 Cohort	4480 male shipyard workers; 861 welders; 908 welded some time; 24 welders in machinery production (SS); workers identified by personnel register with information regarding name, start, and end dates; mainly MS welders Exposure assessment method: records of job title and work history. Welding fumes (mg/m³): MS, 14.5 (1973) and 1.87 (1989); SS, 1.5 (1977) and 7.0–38 (1989); SS grinders, 25.5 (1977). Information on employment outside the shipyard (prior to or between jobs) available from the early 1950s; average length of employment 10.1 yr	Lung	Shipyard welders: employment duration (yr): internal analysis			Age, calendar year	Strengths: information on smoking habits and previous employment; internal comparison of shipyard workers excluding welders Limitations: no quantitative exposure (or semi-quantitative exposure assessment)
			Non-welding shipyard workers (ref.)	36	1		
			< 2	3	2.42 (0.73–8.01)		
			2–4	1	0.66 (0.09–4.85)		
			5–14	1	0.56 (0.08–4.17)		
			≥ 15	4	1.90 (0.67–5.38)		
		Lung	External analysis				
			Welders	9	1.27 (0.58–2.42)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Danielsen et al. (1998) Norway Enrolment 1975/ follow-up 1976–1992 Cohort	428 male welders (23 with siderosis) who had welded for > 10 yr, mostly MMA welding in confined spaces from 15 shipyards, and examined for siderosis in 1975 Exposure assessment method: records, assumed to have long-term exposure to high levels 10 yr or more before 1975; only limited information about smoking habits was available	Lung	Welders	10	1.55 (0.74–2.84)	Age, calendar period	No cases of mesothelioma or asbestosis; electric arc welding on MS was predominant until 1975; gas-shielded welding introduced in the 1970s and SS after 1975 Strengths: presumed high exposure cohort; analysis by time since first exposure Limitations: potential healthy worker effect; welders who died before 1975 or who quit welding due to adverse health effects were not included in the cohort; limited information on smoking habits or exposure to asbestos; small cohort with few exposed cases
		Kidney	Welders	2	1.13 (0.14–4.10)		
		Urinary bladder	Welders	1	0.30 (0.01–1.69)		
		Leukaemia: ICD-7 (code 204)	Welders	1	0.69 (0.02–3.85)		
		Lung	Years since first exposure				
			10–19	0	0 (0–10.91)		
			20–29	3	1.49 (0.31–4.34)		
			30–39	4	1.57 (0.43–4.01)		
			≥ 40	3	1.93 (0.40–5.64)		
		All cancers combined: ICD-7	Welders	32	0.77 (0.53–1.09)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Yiin et al. (2005) USA Enrolment 1952–1992/follow-up 1952–1996 Cohort	13 468 workers; men and women, all races, employed as civilian workers at Portsmouth Naval Shipyard for at least 1 d and monitored for radiation Exposure assessment method: expert judgement; exposure to welding fumes and asbestos (0, none; 1, possible; 2, probable) assigned to each job title/shop combination by an expert panel; cumulative exposure score calculated as the sum of the duration of exposed jobs, weighted by exposure probability	Lung	Total exposure to shipyard welding fumes (based on intensity and duration)			Radiation, age, calendar period, asbestos, SES	Strengths: large cohort; semi-quantitative exposure assessment; adjustment for radiation, asbestos, and SES as a proxy for smoking Limitations: the exposure of interest is radiation; welding fumes analysed as a potential confounder for lung cancer only (no information reported for leukaemia); possible misclassification of exposure; no actual data on smoking habits
			Never	174	1		
			> 0–5[b]	125	1.45 (1.10–1.92)		
			> 5	112	1.50 (1.09–2.06)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Yiin et al. (2007) USA Enrolment 1952–1992/follow-up 1952–1996 Nested case–control	Cases: 1097 deaths from lung cancer Controls: 3291 risk-set-matched controls (3 per case, randomly selected by incidence density sampling) Exposure assessment method: expert judgement; intensity and frequency of exposure to welding fumes (as Fe_2O_3 fumes) and asbestos assessed by an expert panel of 3 industrial hygienists for 3519 job/shop/period combinations. Good concordance, weak inter-rater agreement. Cr and Ni content of welding fumes were also assessed (not used in the analysis). 53% of the study subjects were ever exposed to welding fumes; 64% to asbestos, 8% to Ni and 6% to Cr	Lung	Shipyard welding fumes: multivariate analysis (mg-d/m^3)			Radiation, asbestos exposure, SES, birth cohort	Radiation exposure is the focus of the paper; welding fumes as a confounder was analysed as a continuous variable; unadjusted ORs associated with categorical exposure to welding fumes did not suggest a linear relationship Strengths: detailed exposure assessment; adjustment for asbestos, radiation, SES and birth cohort (surrogates for smoking) Limitations: no actual smoking data; no monitoring data to validate panel estimates
			1000	NR	1.01 (0.98–1.04)		
		Lung	Shipyard welding fumes: individual risk factor effects (mg-d/m^3)			None	
			1000	NR	1.03 (1.0–1.05)		
		Lung	Shipyard welding fume TLV-1 categories: individual risk factor effects (mg-d/m^3)				
			< 0.5	807	1		
			0.5–1	116	1.35 (1.07–1.70)		
			1–2	86	1.58 (1.20–2.07)		
			2–4	40	1.20 (0.82–1.72)		
			≥ 4	48	1.26 (0.88–1.76)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Rinsky et al. (1988) Kittery, Maine, USA 1952–1977 Nested case–control	Cases: 405 white male deaths from malignant neoplasm of bronchus, trachea. or lung; diagnosis based on death certificates Controls: 1215 selected from the same cohort, matched by date of birth, year of 1st employment, and duration of employment 3:1 Exposure assessment method: personnel records indicating the specific shops to which a person had been assigned; job classification and date of each change in employment were used to code work history	Lung	Shipyard: asbestos and welding				Nested case–control study of Portsmouth Naval Shipyard workers; primary research question was the assessment of lung cancer risk due to ionizing radiation emitted from nuclear reactor components Strengths: specific focus on asbestos and welding in addition to radiation exposure; classification of welding exposure by probability (potential, probable) and duration (ever, ≥ 5 yr, ≥ 10 yr) Limitations: limited confounder information; no adjustment for smoking
			Never exposed	138	1		
			Ever exposed	267	1.43 (1.12–1.81)		
			Min 5 yr	152	1.50 (1.11–2.04)		
			Min 10 yr	96	1.38 (0.97–1.98)		
		Lung	Shipyard: Welding shop)				
			Never exposed	364	1		
			Ever exposed	41	1.13 (0.76–1.68)		
			Min 5 yr	28	1.16 (0.73–1.86)		
			Min 10 yr	16	0.83 (0.46–1.53)		
		Lung	Shipyard: probable or potential exposure				
			Never exposed	169	1		
			Ever exposed	236	1.46 (1.17–1.83)		
			Min 5 yr	143	1.41 (1.06–1.87)		
			Min 10 yr	91	1.24 (0.89–1.74)		
		Lung	Shipyard: probable exposure				
			Never exposed	364	–		
			Ever exposed	41	1.13 (0.76–1.68)		
			Min 5 yr	28	1.20 (0.74–1.92)		
			Min 10 yr	16	0.93 (0.50–1.72)		

Table 2.3 (continued)

Reference, location, enrolment period/follow-up, study design	Population size, description, exposure assessment method	Organ site/cancer type	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Stern et al. (1986) USA Enrolment 1952–1977/follow-up 1952–1980 Nested case–control	Cases: 53 deaths from leukaemia (death certificates, checked with medical records) Controls: 212; 4 matched controls by case (exclusion: deaths from haematopoietic or lymphatic malignancies) Exposure assessment method: records of job titles and duration of employment of the different jobs; radiation dose	Leukaemia	Welder	NR	3.19 (1.09–9.37)	Radiation, employment as electrician, employment in jobs exposed to solvents	Strengths: ORs associated with employment as a welder adjusted for radiation exposure, employment as electrician, and jobs exposed to solvents Limitations: crude assessment of exposure
		Leukaemia (myeloid)	Welder	NR	6.23 (1.64–23.64)		
Park et al. (1994) USA Enrolment 1966–1989/follow-up 1978–1988 Cohort	16 197 hourly workers (76% assembly plant, 24% stamping plant); 3887 stamp workers; all hourly employees who worked ≥ 2 yr at 2 automotive assembly plants and a metal stamping plant before 1989 Exposure assessment method: records of six process-related categories for stamping plant; ~25 of the decedents worked in more than one exposure category; welding was performed on sheet metal	Lung	Stamping or assembly plant:			Age, sex, race, chronological time	No information on mesothelioma Strengths: regression analysis and modelling to evaluate similar activities of previous employment, latency, and duration Limitations: no quantitative or semi-quantitative exposure assessment; only 5% of cohort had died due to young ages and short follow-up (11 yr); healthy worker effect in stamping plant; mortality odds ratio; no information on smoking and other potential confounders
			Welding	7	2.73 (1.20–6.30)		
		Lung	Stamping plant: welding lines and welder repair: long latency weighted duration, cumulative exposure (mo)				
			0	8	1		
			1–50	5	[2.00 (0.61–6.61)]		
			51–100	2	[5.81 (0.92–36.8)]		
			All	15	[1.38 (0.56–3.40)]		
		Lung	Stamping plant: adjusted MOR: weighted duration/latency cumulative exposure				
			Long latency	NR	1.90 (0.93–3.90)		
			Long latency	NR	2.73 (1.09–6.90)		
			Short latency	NR	3.95 (1.39–11.00)		
		Lymphatic and haematopoietic	Welders	1	0.99 (0.14–7.20)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Steenland (2002) Illinois, USA Enrolment 1950s–1980s/follow-up mid-1950–1998 Cohort	4459 welders; 4286 never welders; hourly male (90% white) workers with ≥ 2 yr of experience as a production arc welder or welder helper at 3 heavy equipment manufacturing plants Exposure assessment method: records of person monitoring available from 1974 to 1987; smoking data available for subset of workers; TWA geometric mean across plants (particulate levels, 5.5–7.4 mg/m^3; Fe_2O_3, 3–4.1 mg/m^3); average duration of welder 8.5 yr	Lung	Welders vs US population: exposure (yr); 15-yr lag time			Age, race, calendar time	Update of Beaumont & Weiss (1980); 26% of the population had died; potential misclassification of exposure duration since 14% of the population still worked at the end of follow-up; smoking probably cannot explain all the excess of lung cancer in welders; no deaths from asbestosis or nonspecific pneumoconiosis Strengths: exposure monitoring data; non-welder cohort; some data on smoking; exposure to asbestos unlikely Limitations: no quantitative or semiquantitative exposure assessment
			Total mortality	97	1.47 (1.19–1.79)		
			2–5	34	1.39 (0.96–1.94)		
			5–10	23	1.30 (0.82–1.95)		
			10–15	23	1.94 (1.23–2.91)		
			15–20	12	1.65 (0.85–2.88)		
			> 20	15	1.02 (0.57–1.68)		
			Latency < 20	66	1.39 (1.07–1.77)		
			Latency ≥ 20	31	1.66 (1.23–2.36)		
		Lung	Welders vs non-welders: exposure (yr); 15 yr lag time				
			Total mortality	97	1.22 (0.93–1.59)		
			2–5	34	1.10 (0.67–1.81)		
			5–10	23	0.89 (0.49–1.59)		
			10–15	23	1.69 (0.92–3.11)		
			15–20	12	1.63 (0.75–3.51)		
			> 20	15	0.77 (0.29–2.05)		
			Latency < 20	66	1.20 (0.88–1.64)		
			Latency ≥ 20	31	1.10 (0.67–1.79)		
		Larynx	Welders	4	1.42 (0.39–3.62)		
		Kidney	Welders	10	1.84 (0.88–3.38)		
		Urinary bladder	Welders	7	1.71 (0.69–3.53)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Danielsen et al. (1996) Norway Enrolment 1942–1981/follow-up 1953–1992 Cohort	2957 male welders; 606 SS welders; members of the National Registry of Boiler Welders from 385 different businesses who registered before 1981 with information on DOB; foreigners without permanent addresses in Norway excluded; most registered welders welding on MS; MMA welding predominant method in early years Exposure assessment method: records of welder registration information contained the method of welding for certification and information on previous work experience	Lung	Boiler welders: lag time (yr)			Age, calendar period	SS welders: boiler welders ever welding on SS; excess risk of mesothelioma found among boiler welders (3 cases); use of gas shielded and TIG welding increased in 1970s Strengths: exposure misclassification with respect to welders unlikely Limitations: no information on exposure duration, exposure intensity, potential confounders (e.g. asbestos), or smoking; small numbers of exposed cases
			No lag	50	[1.33 (1.00–1.74)]		
			15-yr lag	46	[1.27 (0.94–1.69)]		
		Lung	SS welder: lag time (yr)				
			No lag	6	[1.03 (0.41–2.15)]		
			15-yr lag	2	[0.59 (0.10–1.90)]		
		Lung	Boiler welders: year of first registration				
			1940–1949	7	[1.05 (0.46–2.07)]		
			1950–1959	25	[1.70 (1.12–2.47)]		
			1960–1969	9	[0.75 (0.36–1.37)]		
			1970–1982	9	[2.20 (1.07–4.03)]		
		Lung	SS welder: year of first registration				
			1940–1949	2	[1.66 (0.27–5.50)]		
			1950–1959	1	[0.62 (0.03–3.08)]		
			1960–1969	0	–		
			1970–1982	3	[3.00 (0.76–8.16)]		
		All cancers combined	Boiler welders	269	1.02 (0.90–1.15)		
			SS welders	41	1.00 (0.71–1.35)		
		Nasal cavity and sinuses	Boiler welders	3	3.33 (0.66–9.78)		
		Larynx	Boiler welders	3	0.75 (0.15–2.20)		
			SS welders	0	–		
		Kidney	Boiler welders	19	1.78 (1.07–2.78)		
			SS welders	2	1.18 (0.12–4.24)		
		Urinary bladder	Boiler welders	20	1.05 (0.64–1.63)		
			SS welders	0	0 (0–1.28)		
		Brain	Boiler welders	10	1.02 (0.49–1.88)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Danielsen et al. (1996) cont.)		HL: ICD-7 (code 201)	Boiler welders	3	1.43 (0.29–4.19)		
		NHL: ICD-7 (code 200/2)	Boiler welders	9	0.83 (0.38–1.57)		
		Leukaemia: ICD-7 (code 204)	Boiler welders	11	1.77 (0.89–3.18)		
			SS welders	2	2.00 (0.20–7.20)		
Meguellati-Hakkas et al. (2006) France Enrolment 1978–1994/follow-up 1978–1996 Cohort	34 305 men ever employed as telephone linemen in 1978 and new hires from 1978 to 1994 Exposure assessment method: expert judgement; semiquantitative assessment based on expert assessment of job tasks for specific calendar/time periods; exposure duration was estimated for welding; highest category was 0.04 yr or more	Lung	Duration of arc welding exposure (yr)			Age, calendar period, engine exhaust, PAHs, asbestos	No information on smoking but use of internal analyses decreases concerns Strengths: semi-quantitative exposure assessment; adjustment for exposure to asbestos Limitations: focus of the paper was exposure to asbestos; welding was assessed as a potential confounder; exposure to welding does not seem to be substantial (80% of deaths exposed to less than 0.04 yr of welding)
			0	54	1		
			> 0 to 0.03	127	1.2 (0.8–1.6)		
			> 0.03 to 0.04	64	1.3 (0.8–2.2)		
			> 0.04	63	1.4 (0.7–2.8)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Dunn & Weir (1968) California, USA Enrolment 1954–1957/follow-up 1954–1962 Cohort	68 153 men in all occupations; 10 233 welders and burners; male workers aged 35–64 employed in 14 selected occupational groups were selected from union mailing lists and questionnaires Exposure assessment method: questionnaire; occupational title, employment duration, working conditions, type of welding, and specific exposures associated with particular occupations	Lung	Welders and burners	49	[1.05 (0.79–1.38)]	Age, smoking	Strengths: adjusted for smoking; prospective study Limitations: limited information on occupational co-exposures; short follow-up (7 yr average); referent group was the total population, some of which were exposed to asbestos

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Polednak (1981) Tennessee, USA Enrolment 1943–1974/follow-up 1974 Cohort	1059 white male welders employed at Oak Ridge nuclear facilities during the enrolment period; two subgroups of welders: (1) 536 welders at K-25 Ni alloy pipes (MS and Ni); and (2) 533 welders at Y-12 and X-10 plants conducting various types of welding (SMA, TIG, MIG) Exposure assessment method: records of personal air monitoring (Ni and Fe_2O_3) for different welding procedures: Fe_2O_3, 0.18–0.47 mg/m³; Ni (mg/m³) was highest for MIG/Ni (0.57), intermediate for SMA/Ni (0.13) and MIG carbon steel (0.25), and lowest for TIG welding with Ni (0.04) or carbon steel (0.08). Biomonitoring data (metals) among 33 Ni welders in K-25 facility (0.053 mg/L Ni). Information on smoking available for 33% of workers	Lung	Total cohort of welders	17	1.50 (0.87–2.40)	Age, calendar period	16.7% of workers had died; excess risk of emphysema in total cohort and two subcohorts observed; smoking higher in other plants than K-25; K-25 smoking habits similar to national rates; no information on radiation exposure Strengths: monitoring data, including exposure to Ni, from different types of welding available; long follow-up for 50% of workers; some data on tobacco smoking habits Limitations: small number of cases for employment duration analysis; healthy worker effect (SMR for all causes, 0.87; 95% CI, 0.75–1.01)
			Welders: 15-yr lag	16	[1.76 (1.04–2.80)]		
		Lung: ICD-8	K-25 plant: subgroups of welders				
			Welders	7	1.24 (0.50–2.55)		
			Welders: 15-yr lag	6	[1.26 (0.51–2.62)]		
			Other welders	10	1.75 (0.84–3.22)		
		Respiratory tract: cancer	Total cohort: length of employment as a welder (wk)				
			< 50	10	1.57 (0.75–2.89)		
			≥ 50	7	1.21 (0.49–2.49)		
		Respiratory tract	K-25 plant: length of employment as a welder (wk)				
			< 50	2	[0.62 (0.10–2.05)]		
			≥ 50	5	1.75 (0.57–4.08)		
		Larynx	Total cohort: welders	0	0		
		Brain	Total cohort: welders	3	[1.94 (0.49–5.27)]		
		Leukaemia: ICD-8	Total cohort: welders	1	[0.64 (0.03–3.17)]		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Steenland et al. (1986) Western Washington, USA Enrolment 1950–1973/follow-up 1950–1976 Cohort	3247 welders, 5432 non-welders; male members of a metal trades union/local boilermakers, employed at least 1 d during the period 1950–1973, who had worked for at least for 3 yr Exposure assessment method: job categories from union records	Lung	SMR: Welding	NR	[1.32 (0.99–1.76)]	None	Reanalysis of the cohort reported by Beaumont & Weiss (1980, 1981) using internal reference group Strengths: internal comparison group Limitations: no exposure data
		Lung	Cox: Welding	NR	[1.29 (0.90–1.85)]	Age, employment	
Sorahan et al. (1994) UK Enrolment 1946–1990/follow-up 1946–1978 Cohort	10 438 (total cohort); 401 welders in the fettling shop, 99 welders in pattern/ machine/maintenance/ inspection; men employed for at least 1 yr in 9 English and 1 Scottish steel foundries Exposure assessment method: records of work area and occupational category	Lung	Fettling shop: burning and welding	19	[1.69 (1.04–2.58)]	Age, sex, calendar year	Update of Fletcher & Ades (1984) Limitations: small number of welders; no exposure data
		Lung	Pattern/ machine/ maintenance/ inspection: welding	2	[0.95 (0.16–3.15)]		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Austin et al. (1997) Ohio, USA 1970–1987 Nested case–control	Cases: 231 deaths from lung cancer Controls: 408 selected from the same cohort matched by race, sex, and year of birth using density sampling Exposure assessment method: records of complete work history from plant personnel files; telephone interview for lifestyle characteristics	Lung	Ever welding	10	0.66 (0.29–1.50)	Smoking, job	Strengths: controlling for smoking Limitations: small number of welders; no exposure data; possibly inadequate control group; crude adjustment for smoking (never, former, current, unknown); no adjustment for concomitant occupational exposures in foundry
		Lung	Longest welding job held	7	0.76 (0.28–2.10)	Smoking	
Howe et al. (1983) Canada Enrolment 1965–1977/follow-up 1965–1977 Cohort	43 826 pensioners; 4629 exposed to welding fumes; male pensioners of the Canadian National Railroad company who retired before 1965, were known to be alive in 1965, and who retired during 1965–1977 Exposure assessment method: expert classification of workers exposed to welding fumes, diesel fumes, coal dust, and other exposure based on occupation at retirement	Brain	Individuals exposed to welding fumes	10	3.18 (1.53–5.86)	Age, calendar period	Strengths: not informative Limitations: potential for exposure misclassification; exposure only based on last occupation; no information on type of welding, duration, levels, etc.; findings only reported for brain cancer; no information on smoking or other potential co-exposures

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Bonde et al. (1992) Denmark Enrolment 1964–1984 fathers/follow-up of children (date of birth to date of death, emigration) or 1987 Cohort	27 071 fathers; 5020 children with cancer; Danish fathers who were employed at 74 MS and SS manufacturing companies (as identified by the Danish Pension Fund) for at least 1 year Exposure assessment method: metalworking cohort questionnaire sent through mail, included data on drinking and smoking habits and occupational exposures including the type of welding methods used during three calendar periods; response rate 85%	Childhood cancer	Parental exposure			Age, sex, calendar period	Based on the Danish welding cohort study (Hansen, 1982) Limitations: limited exposure information; small number of cancers occurring in children fathered by welders
			SS welding	2	0.77 (0.13–2.54)		
			MS welding	4	0.93 (0.30–2.24)		

Table 2.3 (continued)

Reference, location, enrolment period/ follow-up, study design	Population size, description, exposure assessment method	Organ site/ cancer type	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Håkansson et al. (2005) Sweden 1985–1994 Nested case–control	Cases: 140 incident cases of tumours of the endocrine glands: adrenal glands (*n* = 29), parathyroid gland (*n* = 67), pituitary gland (*n* = 36), and other subtypes (*n* = 8)	All cancers combined: endocrine glands	Any welding: exposure (h/wk)			Sex, year of birth, solvent exposure, year of inclusion	Focus of the paper is exposure to ELF-EMF Strengths: individual assessment of welding type and welding frequency Limitations: no assessment of exposure to welding fumes; small number of exposed cases in subgroups
			Ever	25	2.1 (1.3–3.5)		
			> 0–10	8	1.9 (0.8–4.4)		
			> 10–30	7	1.9 (0.8–4.6)		
			> 30–40	10	2.5 (1.2–5.5)		
			Trend test *P* value, 0.01				
	Controls: 1306 matched by sex and year of birth (3-year intervals) Exposure assessment method: questionnaire; assessment at the individual level from questionnaire and telephone interview with a contact person at the workplace; blind as to case–control status	All cancers combined: endocrine glands	Resistance welding: exposure (h/wk)				
			Ever	7	1.1 (0.5–2.4)		
			> 0–10	3	1.2 (0.3–4.3)		
			> 10–30	4	1.4 (0.5–4.1)		
			> 30–40	0	0 (0–0)		
			Trend test *P* value, 0.63				
		All cancers combined: endocrine glands	Arc welding: exposure (h/wk)				
			Ever	20	2.9 (1.6–5.3)		
			> 0–10	6	2.2 (0.8–6.0)		
			> 10–30	5	2.8 (0.9–9.1)		
			> 30–40	9	3.8 (1.6–9.3)		
			Trend test *P* value, 0.00				

[a] Included in "ever stainless steel welders"

[b] Total exposures (based on intensity and duration) of welding fumes were arbitrarily classified into three categories (value of 0, .0–5 and .5)

B[*a*]P, benzo[*a*]pyrene; CI, confidence interval; Cr, chromium; Cr(VI), hexavalent chromium; d, day(s); DOB, date of birth; ELF-EMF, extremely low frequency electromagnetic field; Fe_2O_3, iron oxide; h, hour(s); HL, Hodgkin lymphoma; IARC, International Agency for Research on Cancer; ICD, International Classification of Diseases; MAG, metal active gas; MIG, metal inert gas; MMA, manual metal arc; mo, month(s); MOR, mortality; odds ratio; MS, mild steel; NHL, non-Hodgkin lymphoma; Ni, nickel; NO_x, nitrogen oxides; NR, not reported; NS, not significant; PAH, polycyclic aromatic hydrocarbon; SES, socioeconomic status; SIR, standardized incidence ratio; SMA, shielded metal arc; SMR, standardized mortality ratio; SS, stainless steel; TIG, tungsten inert gas; TWA, time-weighted average; vs, versus; wk, week(s); WIG, Wolfram-Inert-Gas welding; yr, year(s)

Table 2.4 Cancer and welding or exposure to welding fumes: studies included in the IARC multicentre cohort (Simonato et al., 1991)

IARC subcohorts	IARC cohort (population)	Publications of the IARC subcohorts	Comments
Denmark	4642	Hansen et al. (1996) 6180 male welders (not shipyard); 105 lung cancer cases	Follow up until 1968–1986; larger cohort
		Lauritsen & Hansen (1996) 94 lung cancer cases from Hansen et al. (1996)	Case–control analysis; adjusted for smoking
		Sørensen et al. (2007) 4536 male welders (non-shipyard); incidence	Follow-up 1968–2003 (cohort restricted to those who started working by 1960); longer follow-up; more detailed analysis on welding types; adjusted for smoking and asbestos
England	393	No separate report published	–
Finland	1808	Tola et al. (1988) 1689 male welders (1308 shipyard, 381 machine shop); mortality	Smoking data; machine shop only SIR (minimal exposure to asbestos); complete overlap in study population with the Simonato et al. (1991) publication
France	1190	Moulin et al. (1993) 2721 male welders; mortality	Smoking data; internal referent group; expanded and longer follow-up
Germany	1199	Becker (1999) 1213 welders; mortality	Internal referent group; indirect assessment of asbestos; longer follow-up
Italy	447	Merlo et al. (1989) 527 welders; mortality Puntoni et al. (2001) 493 welders; mortality	Probable overlap between these studies and the Italian subcohort, and between these two studies; extent of overlapping unknown
Norway	737	No separate report published	–
Scotland	237	No separate report published	–
Sweden	439	Milatou-Smith et al. (1997) 233 male welders exposed to high levels of Cr; 208 railroad track male welders; incidence	Longer follow-up; separate analysis for the two different cohorts

Cr, chromium; IARC, International Agency for Research on Cancer; SIR, standardized incidence ratio or setting (shipyards, MS, SS). A limitation was the lack of data on asbestos exposure, since confounding by asbestos may partly explain the excess of cancer of the lung, and that exposure–response analyses were not reported in the publication although they were conducted.]

(ii) IARC subcohorts

See Table 2.4

Studies of the IARC subcohorts overlapped with the multicentre cohort, had smaller sample sizes, and were overall considered to be less informative than the pooled analyses. However, they provided additional data on smoking habits and asbestos exposure, and/or an extended follow-up. (See Table 2.4 for information on the overlap between the IARC study and the separate reports of its subcohorts.)

The French subcohort included in the IARC study was further extended by adding new factories and by updating the follow-up from 1975 to 1988 (Moulin et al., 1993). In addition, a group of manual workers in the same factories was used as an internal reference group and smoking data were collected. The relative risk (RR) of cancer of the lung for welders compared with the reference group was 1.29 (non-significant, *P* value and CI not reported). [The Working Group noted that the inclusion of shipyard workers, potentially exposed to asbestos, in the reference group may have resulted in an underestimation of the relative risk.] An indirect adjustment suggested that the slight differences in smoking habits between welders and referents would result in a relative risk of 1.06. Analyses by type of welding showed a higher standardized mortality ratio in MS than in SS welders. An increase in mortality from cancer of the lung with duration and time since first employment was observed only in MS welders [the three deaths from cancer of the lung in the group of SS welders did not allow meaningful analysis]. No deaths from cancer of the pleura occurred among welders (0.41 expected), whereas three deaths from cancer of the pleura were identified in the reference group, all shipyard workers (expected, 0.26). [The Working Group noted that these data suggest that exposure to asbestos is not likely to explain the lung cancer excess observed in non-shipyard MS welders. No actual data on asbestos exposure were available.]

Mortality from cancer of the lung was further evaluated in the two Swedish subcohorts (Sjögren, 1980; Sjögren et al., 1987; Milatou-Smith et al., 1997): a cohort of 233 SS welders, who welded mainly with coated electrodes and were exposed to high concentrations of hexavalent chromium; and a cohort of 208 railway track welders, exposed to MS fumes with low concentrations of hexavalent chromium. Exposure to asbestos was assumed to be very low in the two cohorts [the occurrence of mesothelioma was not reported]. When compared with the national population, an elevated standardized mortality ratio was observed in SS welders, whereas mortality from cancer of the lung was decreased in MS welders. The relative risk of cancer of the lung in SS welders compared with the group of MS welders was 3.98 (95% CI, 0.84–18.80). [The small numbers of deaths from cancer of the lung limited the interpretation.]

The subcohort of German arc welders (Becker et al., 1985) was successively updated by Becker et al. (1991) and Becker (1999). A cohort of turners was also followed up as an internal comparison group. In the last follow-up (Becker, 1999), elevated standardized mortality ratios were found among welders for cancers of the lung (SMR, 1.21; 95% CI, 0.80–1.75), bladder (SMR, 2.08; 95% CI, 0.67–4.84), and brain (SMR, 2.02; 95% CI, 0.55–5.19). Mortality from cancer of the lung was also higher in welders than in the comparison group (RR, 1.30; 95% CI, 0.80–2.12). No clear trend with duration of employment or time since first employment was suggested. Analyses by welding technique or by average daily welding time did not reveal strong differences in mortality from cancer of the lung or from other cancer sites, with the exception of an increased standardized mortality ratio of cancer of the brain among welders only welding with coated electrodes (SMR, 6.18; 95% CI, 1.88–15.85). Seven deaths from mesothelioma occurred among welders (0.6 expected; SMR, 11.67; 95% CI, 4.69–24.04), compared with one death in the comparison group (1.0 expected). An indirect assessment of asbestos-related cancers showed that the increased mortality from cancer of the lung among welders could be entirely explained by asbestos exposure. [The Working Group agreed that exposure to asbestos is likely to explain the excess of cancer of the lung observed in this German part of the IARC cohort.]

Cancer incidence among Danish welders employed in SS or MS industrial companies has been reported (Hansen, 1982; Hansen et al., 1996; Lauritsen & Hansen, 1996; Sørensen et al. 2007). Shipyard welders were specifically excluded. Data on occupational and smoking history were collected by questionnaire at baseline. The study by Sørensen et al. (2007) is considered to be the most informative report of this population due to the longer follow-up period, better exposure assessment, reduced left truncation by excluding workers hired before 1960, and adjustment for tobacco smoking and exposure to asbestos; the analyses of incidence of cancer of the lung by Hansen et al. (1996) and the nested case–control study of mortality from cancer of the lung by Lauritsen & Hansen (1996) are therefore not reviewed separately. Findings for other cancer sites are reported from Hansen et al. (1996) because Sørensen et al. (2007) did not report the data (see Table 2.4 for the overlap between these studies). In the first report (Hansen et al., 1996), standardized incidence ratios for other cancer sites of interest were 1.19 (95% CI, 0.78–1.74; 26 exposed cases) for the urinary tract and 0.92 (95% CI, 0.50–1.54; 14 exposed cases) for lymphatic tissues. The number of cancers of the pleura did not exceed the expected number [the numbers were not reported]. Sørensen et al. (2007) reported data mainly for incidence of cancer of the lung, and incorporated a specific assessment of exposure to welding fumes [different from that used in the IARC multicentre study] based on a JEM using all exposure measurements specific to the calendar year in Denmark. An internal analysis was also conducted, adjusted for age, smoking, asbestos exposure from welding, and jobs prior to enrolment.

The standardized incidence ratio for cancer of the lung was increased in the whole cohort (SIR, 1.35; 95% CI, 1.06–1.70) and was higher among the group of welders who only welded MS (SIR, 1.59; 95% CI, 1.14–2.16) than among the group of ever SS welders (SIR, 1.15; 95% CI, 0.78–1.60). However, an elevated ratio was observed in ever SS welders who had ever conducted manual metal arc (MMA) welding (SIR, 1.46; 95% CI, 0.95–2.16).

In the internal comparison, the hazard ratio of cancer of the lung was not increased in ever SS welders when compared with MS welders who never welded SS (HR, 0.86; 95% CI, 0.52–1.42). The risk did not increase with increasing duration for any type of welding. The risk increased with cumulative exposure to welding fume particulates among ever SS welders, while no clear positive trend was found among MS welders who never welded SS. In the highest cumulative exposure category of SS welders, the adjusted hazard ratio was 2.34 (95% CI, 1.03–5.28). [The strengths of this study were the long follow-up, individual data on asbestos exposure and smoking, and individual semi-quantitative exposure assessment to welding fumes.]

(b) Shipyard workers

Seven cohort studies of shipyard workers which assessed exposure by occupation as a welder, including one in England, four in Norway, and two in Italy, were identified. The two Italian shipyard studies may overlap with each other (Merlo et al., 1989; Puntoni et al., 2001) and with the Italian subcohort of the IARC study [this is not explicitly reported in the publications]. In addition, a series of studies of workers at a naval shipyard who overhauled nuclear submarines was identified in which semi-quantitative or quantitative exposure to welding fumes was assessed. Shipyard welders in these cohorts were primarily MS welders and asbestos was widely used in the shipyards. The IARC study (see Section 2.4.1 (a)) also reported a risk estimate for cancer of the lung and shipyard welders.

Cancer mortality was evaluated in a cohort of four craftsmen groups (1027 welders, 235 caulker burners, 557 platers, and 1670 electricians) employed in a shipyard in north-east England (Newhouse et al., 1985). Standardized mortality ratios (using local rates) for cancer of the lung were 1.13 (95% CI, 0.80–1.57; 26 exposed cases) for welders and 2.32 (95% CI, 1.33–3.74) for caulker burners. Caulker burners performed burning and oxypropane cutting tasks and were exposed to fumes that were similar in magnitude and composition to welding fumes; however, these tasks were performed outside, most likely reducing exposure to the fumes. No excess risk of cancer of the lung was found for the two other groups of craftsmen. [Although there were indicators of potential confounding from asbestos (mesotheliomas) or smoking, these indicators may not explain the excess risk of cancer of the lung because they occurred in craftsmen subgroups with and without increased risk of cancer of the lung. The study was limited by incomplete records of employment, the mobility of workers in moving to other shipyards, and short follow-up time (during which only 15.7% of the workforce had died).]

(i) Shipyards in Norway

Using a somewhat similar study design, three cohort studies reported on cancer incidence of welders employed at three different Norwegian shipyards (Melkild et al., 1989; Danielsen et al., 1993, 2000). The cohorts included all male workers employed as welders, identified from the shipyard personnel records for the specific enrolment dates that covered several decades (from the 1940s to early 1980s). Follow-up began in 1953 with the establishment of the Norway Cancer Registry; cancer cases that occurred from the first enrolment date (1940s) to 1953 were not known. Most of the welders were MS welders, which was the predominant type of metal welding used in Norway until the mid-1970s. Asbestos was used in the shipyards until the 1970s. Little information on the smoking habits of cohort members was available. [The Working Group noted that exposure monitoring data was not used in the exposure assessment. The limitations of the studies included potential confounding from tobacco smoking and exposure to asbestos. No mesotheliomas occurred among welders in all three cohorts.]

The earliest cohort study included MS workers at a shipyard in south-west Norway (Melkild et al., 1989). Compared with non-welding Norwegian men, welders had an elevated risk of cancer of the lung (SIR, 2.21; 95% CI, 0.88–4.54; 7 exposed cases) which was concentrated among workers employed as welders for 1–5 years.

The second cohort study included MS welders at a shipyard on the west coast of Norway (Danielsen et al., 1993). In external 15-year lagged analysis, the standardized incidence ratio for cancer of the lung was 3.08 (95% CI, 1.35–6.08; 8 exposed cases) for all welders and somewhat higher among welders exposed to “high” (SIR, 3.75; 95% CI, 1.38–8.19; 6 exposed cases) or “very high” levels (SIR, 4.0; 95% CI, 1.10–10.20; 4 exposed cases). Similar results were found in an internal analysis that used other shipyard workers (who were not welders, burners, or administrative workers) as the referent group and a 10-year lagged time. There was some evidence of an exposure-duration–response in the internal analysis (unlagged and 10-year lagged); risks were higher among those that had worked as welders for 5 years compared with those that had worked for fewer years.

A 1984 survey of smoking habits found that daily smoking was 10–20% higher among Norwegian shipyard production workers and welders than the general public, and these smoking differences were estimated to explain a 25% increase risk (e.g. SIR, ~1.25). [The advantages of this study were lagged analysis by exposure to "high" and "very high" levels (although based on duration), internal analyses which helped to mitigate concerns for tobacco smoking and exposure to asbestos, and information, although limited, on smoking habits. Non-welding shipyard workers were presumed to have similar smoking habits as for welders.]

The third cohort was of MS welders at a shipyard on the island Stord (Danielsen et al., 2000). An excess risk of cancer of the lung occurred in both external (SIR, 1.27; 95% CI, 0.58–2.42) and internal analyses, using other shipyard workers as a referent, among welders employed for less than 2 years (RR, 2.42; 95% CI, 0.73–8.01; 3 exposed cases) and for more than 15 years (RR, 1.90; 95% CI, 0.67–5.38; 4 exposed cases). [The small numbers of cases limited the ability to look at employment-duration–response relationships.] The differences in risk of cancer of the lung among different types of shipyard workers were not explained by previous work history. In 1976 and 1984 surveys of the shipyard, the proportion of shipyard welders who were daily smokers was similar to shipyard non-welders, and approximately 10% higher than Norwegian men.

Another study in Norway investigated cancer incidence among shipyard welders employed for more than 10 years at 15 shipyard companies, and examined for siderosis in 1975 (Danielsen et al., 1998). Welders who had quit welding before 1975 because of health problems were not included in the study. The predominant welding technique was electric arc on MS; SS welding was introduced after 1975. Welders had an increased risk of cancer of the lung (SIR, 1.55; 95% CI, 0.74–2.84; 10 exposed cases) compared with non-welding Norwegian males. In analyses by time since first exposure, the highest risk was among those welders for whom 40 years had passed since their first exposure (SIR, 1.93; 95% CI, 0.40–5.64; 3 exposed cases); however, the number of exposed cases was small for each exposure period. No cases of cancer of the lung occurred among 23 welders who had siderosis. Asbestos was used in shipyards, although no cases of mesothelioma were reported among welders. [The Working Group noted the potential for a healthy worker effect, and potential confounding from exposure to asbestos and tobacco smoking.]

(ii) Shipyards in Genoa, Italy

Cancer mortality was evaluated in a cohort of active and retired 274 oxyacetylene (mainly MS) welders and 253 electric arc (mainly SS) welders employed at a shipyard in Genova, Italy, from 1930 to 1980 (Merlo et al., 1989). Welders were presumed to be potentially exposed to low concentrations of asbestos fibres according to company records. [The Working Group questioned the validity of this statement.] An increased risk of mortality due to cancer of the lung (reported as respiratory tract) was found among oxyacetylene welders in both external (SMR, 2.34; 95% CI, 1.21–4.09; 12 exposed cases) and internal analyses (RR, 2.45; 95% CI, 0.77–7.83) using electric arc welders (mainly SS) as the referent group, since they mainly worked outdoors and were therefore presumed to have lower exposures. Oxyacetylene welders worked inside oil tankers, and were assumed to be exposed to higher levels of gases and fumes than electric arc workers who worked in open spaces. No increased risk of cancer of the lung was found among electric arc workers compared with the general population. Excess mortality from cancer of the lung due to tobacco smoking was modelled to be equivalent to an excess relative risk of 21–30% (depending on the smoking habits of the referent population); information on smoking habits was ascertained from a 1986 survey. [The Working Group noted that the use of internal analyses reduces concerns for potential confounding from lifestyle factors such as tobacco smoking and exposure to asbestos, which were thought to be similar between the two groups of welders. Follow-up did not start until 30 years after first date of enrolment, meaning that deaths resulting from cancer of the lung during 1930–1960 may have been missed.]

The mortality in a cohort of shipyard workers employed at the harbour of Genoa, Italy, from 1960 to 1980, including 267 arc welders and 228 gas welders, was studied and subsequently updated by Puntoni et al. (1979, 2001). Mortality from cancer of the lung was increased in both arc welders (SMR, 1.64; CI not reported) and gas welders (SMR, 1.57). Electric arc welders also showed increased mortality for cancers of the bladder (SMR, 2.74) and kidney (SMR, 4.0). Elevated standardized mortality ratios were observed among gas welders for cancers of the larynx (SMR, 2.0) and kidney (SMR, 3.57). Three deaths from cancer of the pleura (SMR, 3.77) and one death from asbestosis were observed among electric arc welders; one death from cancer of the pleura (SMR, 1.69) occurred among gas welders. [The Working Group inferred from the cancer of the pleura and asbestosis deaths that this cohort may have experienced substantial asbestos exposure, which limits the interpretation of excesses of cancer of the lung in welders. The Working Group also suspected some overlap with the study by Merlo et al. (1989) described in the paragraph above.]

(iii) Portsmouth Naval Shipyard

The risk of cancer of the lung and leukaemia was investigated in a cohort of workers monitored for radiation exposure at the Portsmouth Naval Shipyard in Maine, USA, initiated to study the effects of ionizing radiation exposure (Yiin et al., 2005). The main objective was to explore dose–response relationships between ionizing radiation and risk of cancer, while adjusting for previously unanalysed confounders. Semi-quantitative exposure scores were calculated for asbestos and welding fumes. After adjustment for socioeconomic status (as a proxy for smoking) and exposure to asbestos and radiation, the risk of cancer of the lung increased for workers exposed to welding fumes, although the relative risks were similar in the low (RR, 1.45; 95% CI, 1.1–1.92) and high (RR, 1.5; 95% CI, 1.09–2.06) categories of exposure.

A nested case–control study of cancer of the lung (Yiin et al., 2007) was also conducted in this cohort, extended to non-radiation workers, with an improved quantitative assessment of exposure to welding fumes, asbestos, and the chromium and nickel content of welding fumes (Seel et al., 2007). This study superseded a previous nested case–control study of cancer of the lung within the same cohort (Rinsky et al., 1988). Exposure estimates in the study population (Zaebst et al., 2009) showed that a large proportion of workers were exposed to welding fumes (53%) and to asbestos (64%). As most of the welding in this shipyard was on MS, exposure to chromium and nickel in welding fumes was much less frequent (6% and 8% of the workers, respectively), and these exposures were not considered in the epidemiological analysis. Socioeconomic status and birth cohort were used as a surrogate for smoking. When examining risk of cancer of the lung with exposure to welding fumes on a continuous scale (per 1000 mg-days/m^3), the multivariate odds ratio was 1.01 (95% CI, 0.98–1.04).

Although mortality from leukaemia was also examined in this cohort, neither the cohort analysis (Yiin et al., 2005) or the nested case–control study on leukaemia (Kubale et al., 2005) examined the association with exposure to welding fumes. However, in a previous case–control study of leukaemia within the Portsmouth Naval Shipyard cohort (Stern et al., 1986), an increased risk of leukaemia (OR, 3.19; 95% CI, 1.09–9.37), particularly myeloid leukaemia (OR, 6.23; 95% CI, 1.64–23.64), was found among welders after adjustment for radiation exposure, employment as electrician, and exposure to solvents. [The Working Group noted that the focus of the Portsmouth Naval Shipyard study was ionizing radiation exposure; despite the comprehensive exposure assessment, the effects of exposure to welding fumes were not explored in detail.]

(c) Other welding industries

The other cohort studies evaluated cancer mortality or incidence in welders in a variety of industries including heavy equipment manufacturing plants, automobile assembly, stamp and engine plants, foundries, metal shops, telephone line workers, and nuclear plants. Some studies assembled workers from a large number of companies by using occupational registries or union records. Studies reporting on cancer of the lung are organized based on information regarding potential exposure to asbestos, and then by chronological date. Studies of welders with minimum exposure to asbestos include a cohort of automobile assembly and stamp workers (Park et al., 1994) and a cohort of heavy equipment manufacturing workers (Steenland, 2002). Exposure to asbestos may have been more substantial in the Norwegian study of boiler welders (Danielsen et al., 1996) and in a study of French telephone line workers (Meguellati-Hakkas et al., 2006). The remaining studies provided no or little information (such as use of asbestos or cases of mesothelioma) to evaluate potential confounding from exposure to asbestos (Dunn & Weir, 1968; Polednak, 1981; Steenland et al., 1986; Sorahan et al., 1994; Austin et al., 1997). With the exception of the French study of telephone line workers which assessed cumulative exposure to welding fumes, all of the other studies assessed exposure by occupation as a welder.

Park et al. (1994) conducted a cohort study of hourly employees who worked at an automotive metal stamping and assembly complex. Welding in the stamp plant was performed on sheet metal. Using controls who did not die from cancers of the lung, stomach, pancreas, and haematopoietic system, standardized mortality odds ratio (MOR) for cancer of the lung was significantly elevated for welding (MOR, 2.73; 95% CI, 1.20–6.30; 7 exposed deaths) and increased with increasing duration of employment in welding areas (although based on a small number of deaths). The highest mortality odds ratios were reported in logistic regression models that combined previous welding employment with employment in the stamping plant and models using short latency weighting. [The Working Group noted that potential exposure to asbestos was limited to a few workers in assembly operations and unlikely to be a concern for welders. No information was available on smoking habits; however, internal analyses helped to mitigate concerns from tobacco smoking. The limitations of the study included the healthy worker effect, a young cohort, and a short follow-up (5% of the cohort had died).]

Cancer mortality was evaluated in a cohort of male MS welders and non-welders employed at three heavy equipment manufacturing plants in Illinois, USA. Importantly, these workers were not exposed to asbestos, nickel, or chromium (Steenland, 2002). Workers who only worked as flame-cutters or burners, or on maintenance, were excluded. The 2002 study updated the findings of the original study (Steenland et al., 1991) with 10 years of additional follow-up. The average time since first exposure was 20 years, and 23% of the population had died. An excess risk of mortality from cancer of the lung was observed among welders compared with men in the general population (SMR, 1.47; 95% CI, 1.19–1.79; 97 deaths) or with male non-welder workers (standardized rate ratio (SRR), 1.22; 95% CI, 0.93–1.59). In internal analysis using a 10-year lagged time, standardized rate ratios increased with increasing employment duration with the exception of the longest employment duration, which showed no increased risk. Trends for years of exposure (*P* for trend, 0.33) or log years of exposure (*P* for trend, 0.17) were not statistically significant. Based on a cross-sectional survey, welders and non-welders in the cohort smoked more than the general population. The authors estimated that smoking differences would result in a risk ratio of 1.08 between welders and non-welders within the cohort, and 1.23 between cohort welders and the US population. [The strengths of the study included an internal comparison group, information on smoking habits, little or no exposure to asbestos, a relatively large number of cases, and adequate follow-up. The major limitation was the lack of semiquantitative or quantitative exposure assessment to welding fumes.]

Danielsen et al. (1996) evaluated cancer incidence among welders listed in the Norway Registry of Boiler Welders from 385 different businesses throughout Norway. Standardized incidence ratios for cancer of the lung were 1.33 (95% CI, 1.00–1.74; 50 exposed cases) for all boiler welders and 1.03 (95% CI, 0.41–2.15; 6 exposed cases) for the subset of SS welders. In analysis by date of first registration, boiler welders who first registered during the periods 1950–1959 and 1970–1982 had an increased risk of cancer of the lung. Asbestos was used until the mid-1970s and an excess of pleural mesotheliomas was observed among welders (3 cases among boiler welders and 1 case among SS welders). The standardized incidence ratio for cancer of the kidney for boiler welders was 1.78 (95% CI, 1.07–2.78; 19 exposed cases).

A cohort study of cancer mortality was conducted among 34 305 French male telephone line workers exposed to low concentrations of asbestos during the installation of telephone cables (Meguellati-Hakkas et al., 2006). The cohort included both prevalent hires (as of 1978) as well as men newly hired during 1978–1994, and the workers were followed until 1996. In multivariable models adjusting for age, calendar period, and occupational co-exposures (asbestos, polycyclic aromatic hydrocarbons (PAHs), and engine exhausts), small, non-significant elevated risks of cancer of the lung were observed in all cumulative exposure categories of arc welding; the risk was somewhat higher in the longest exposure duration category (RR, 1.4; 95% CI, 0.7–2.8; 63 deaths). Exposure to asbestos but not engine exhaust or PAHs was associated with mortality from cancer of the lung in this study. [The advantages of this study were the use of a semiquantitative exposure assessment to arc welding and the large numbers of deaths from cancer of the lung for mortality analysis. The focus of the study was exposure to asbestos; exposure to welding fumes was included in the analyses as a potential confounder for the association with cancer of the lung. Exposure to welding fumes did not appear to be substantial in this cohort; 80% of deaths occurred in workers exposed to less than 0.04 cumulative exposure years of welding.]

Dunn & Weir (1968) conducted a prospective study of male workers employed in several different occupation groups in California, USA, chosen based on case–control studies which suggested a possible link with risk of cancer of the lung. The workers were selected from union mailing lists and questionnaires. No excess deaths from cancer of the lung occurred among the combined category of welders and burners compared with the expected deaths (adjusted for age and smoking) for the total study population (e.g. workers). [The Working Group noted that expected numbers included workers that were exposed to asbestos, and that the follow-up period was short (average 7 years).]

A cohort study was conducted of white male welders employed at three Oak Ridge nuclear plants in the USA (Polednak, 1981). The welders were divided into two groups: the first group worked at a facility (K-25 plant) that welded nickel-alloy pipes; and the second group (“other welders”) worked with MS, SS, and other metals. Mortality from cancer of the lung was elevated in both type of welders, and was somewhat higher among the "other welders" group (SMR, 1.75; 95% CI, 0.84–3.22; 10 exposed deaths) than the nickel-alloy workers ([SMR, 1.26; 95% CI, 0.51–2.62]; 7 exposed deaths); most of the risk in the latter group occurred in workers who had been employed for more than 50 weeks. [The available data on tobacco smoking suggested that a greater proportion of welders smoked compared with the general public, and tobacco smoking may be a potential confounder for cancer of the lung in this welder group. In contrast, nickel-alloy workers had smoking habits which were similar to that of the general public. The excess risk of cancer of the lung among K-25 plant workers may have been due to exposure to nickel; concentrations of nickel were above the National Institute for Occupational Safety and Health recommended standard of 0.015 mg/m^3. Other study limitations were the small numbers of exposed cases and the potential for a healthy worker effect (SMR, 0.87 for all causes). No information was provided about exposure to ionizing radiation.]

Sorahan et al. (1994) updated a cohort of foundry workers previously investigated by Fletcher & Ades (1984) and Sorahan & Cooke (1989). Workers were classified into 25 occupational categories, according to the first job held. An increased standardized mortality ratio for cancer of the lung was shown for "burning and welding" in the fettling shop, but higher standardized mortality ratios were found for other occupations in the fettling shop. Welding in "pattern/machine/maintenance/inspection" was not associated with elevated mortality from cancer of the lung. The numbers of deaths from cancer of the stomach were below expectations in both groups. Mortality from other cancers was not reported by occupational category. [The Working Group noted that the cohort included only a small number of welders, and no exposure data were available. However, at least some workers would have been exposed to foundry processes.]

A cohort of members of a metal trade union, including welders and non-welders, was investigated by Beaumont & Weiss (1980, 1981). Welders had an elevated mortality from cancer of the lung (SMR, 1.32), which increased with time since first employment (SMR, 1.74 for 20 years since first employment). A reanalysis of these data (Steenland et al., 1986) using Cox regression estimated the cancer of the lung rate ratio for welders versus non-welders as 1.29 (P = 0.17; CI not reported). [No exposure data were available.]

A nested case–control study of cancer of the lung (231 deaths, 408 controls) was conducted among workers at a foundry and two engine plants (Austin et al., 1997). Work histories were obtained from plant personnel files; smoking data were collected by telephone interview of next-of-kin for the cases, and of the subject (64%) or a next-of-kin for controls. After adjustment for smoking, no elevation of mortality from cancer of the lung was found in the welding group. This study did not identify any specific job or plant area with an increased risk of cancer of the lung.

(d) Less informative industrial cohort studies

The Working Group reviewed several additional studies of welders that were considered to be less informative because they were not specific to welding (McMillan & Pethybridge 1983; Silverstein et al., 1985; Verma et al., 1992; de Silva et al., 1999; Krstev et al., 2007; Wu et al., 2013) and/or had other limitations in the design or analysis (McMillan & Pethybridge, 1983; Verma et al., 1992; de Silva et al., 1999). Two studies were limited in their ability to detect an association between cancer of the lung and welding; one study included some welders in the reference group (McMillan & Pethybridge, 1983) and the other study was very small and had inadequate follow-up (de Silva et al., 1999). In the study by Verma et al. (1992), welders worked in a tank house in the vicinity of tar-laying operations and were exposed to high levels of PAHs (which were measured in the study).

(e) Cohort studies that did not report on cancer of the lung

See Table 2.3

Howe et al. (1983) reported on mortality from cancer of the brain of a cohort of male pensioners exposed to welding fumes during employment with the Canadian National Railway company over the period 1965–1977. The standardized mortality ratio for cancer of the brain was 3.18 (95% CI, 1.53–5.86; 10 exposed deaths). [The Working Group noted that there was potential for exposure misclassification due to a lack of detailed information or lifetime work history. No information was available on which occupations were considered to entail exposure to welding fumes, or on smoking and potential co-exposures.]

A study of paternal exposure to welding and childhood malignancies was conducted among a cohort of men employed at 74 Danish MS or SS manufacturing companies (Bonde et al., 1992). The study was based on the Danish welding cohort study (Hansen et al., 1996). Standardized incidence ratios were close to unity for childhood cancers for offspring of SS welders (2 cases of cancer) and those of MS welders (4 cases of cancer). [The study had limited power to detect childhood cancer risks.]

To examine cancer incidence in workers exposed to high levels of extremely low frequency electromagnetic fields (ELF-EMF), a cohort with an elevated prevalence of electric resistance welders was established (Håkansson et al., 2002). The cohort comprised all subjects ever employed during 1985–1994 in industries assumed to use electric resistance welding (537 692 men and 180 29 women). A case–control study on tumours of the endocrine glands was nested in this cohort, including 140 cases and 1306 controls frequency-matched by sex and age (Håkansson et al., 2005). An increased risk of tumours of the endocrine glands was found among welders (OR, 2.1; 95% CI, 1.3–3.5), which was limited to arc welding (OR, 2.9; 95% CI, 1.6–5.3). There was no evidence of an association with electric resistance welding (OR, 1.1; 95% CI, 0.5–2.4). Among arc welders, the risk increased with the average number of welding hours per week (*P* for trend, 0.63). Elevated odds ratios were observed for all subtypes (adrenal glands, parathyroid gland, pituitary gland). [Considering the elevated risks of arc welding and not electric resistance welding, ELF-EMF does not appear to explain these results.]

2.4.2 Population-based cohorts

See Table 2.1

Several studies evaluated the risk of exposure to welding fumes or occupation as a welder in population-based cohorts. In general, there was lower confidence in the exposure information than from industrial cohorts. The studies include: (1) three studies that used a JEM to assess exposure to welding fumes based on occupational questionnaire data; (2) two record-linkage studies; (3) a prospective cohort evaluating occupation and different types of cancer in Europe; and (4) a prospective cohort study evaluating the incidence of cancer of the lung among frequent smokers enrolled in a lung screening randomized trial.

A cohort of 869 men from the town of Zutphen, the Netherlands, born between 1900 and 1920, was used to compare the performance of different methods of exposure assessment in an analysis of incidence of cancer of the lung (Kromhout et al., 1992). Exposure to welding fumes and soldering fumes was assessed with a general JEM (Pannett et al., 1985) and a population-specific JEM, developed from self-reported exposures collected in a sample of the cohort. No clear associations were found between risk of cancer of the lung and exposure to fumes evaluated by the general JEM. When exposures were assessed by the population-specific JEM, elevated hazard ratios for cancer of the lung, adjusted for smoking, were found for exposure to welding fumes (HR, 1.93; 95% CI, 1.05–3.55) and soldering fumes (HR, 2.24; 95% CI, 1.17–4.29).

A population-based cohort study was conducted in the Netherlands among 58 279 men, aged 55–69 years, who completed a self-administered questionnaire in 1986 and were followed up for incidence of cancer of the lung until 1990 (van Loon et al., 1997a). [The follow-up of this cohort was short and exposure was assessed retrospectively at baseline.] After adjustment for smoking, diet, and other occupational exposures, the relative risk for ever exposure to welding fumes was not increased (RR, 0.86; 95% CI, 0.46–1.58), and no clear trend was observed with the score of cumulative exposure. In the same cohort, the adjusted relative risk for incidence of cancer of the prostate (Zeegers et al., 2004) was 1.41 (95% CI, 0.51–3.88; 12 exposed cases) for those ever employed as a welder.

The cohort of 1.2 million economically active Finnish men who participated in the 1970 national census was followed for incidence of cancer of the lung during 1971–1995 (Siew et al., 2008). The Finnish job-exposure matrix (FINJEM) was linked to the occupation held for the longest time up to 1970 to assess cumulative exposure to welding fumes, iron fumes, asbestos, silica, chromium, nickel, lead, benzo[*a*]pyrene, and smoking. Relative risks adjusted for age, smoking, socioeconomic status, and exposure to asbestos and silica were estimated using the Poisson regression. The standardized incidence ratio of cancer of the lung was 1.31 (95% CI, 0.84–1.95) among welders in the building industry, 1.05 (95% CI, 0.69–1.55) for welders in shipyards, 1.39 (95% CI, 1.14–1.69) among welders not otherwise specified, and 0.95 (95% CI, 0.78–1.15) among SS welders. The risk for cancer of the lung increased as the cumulative exposure to welding fumes increased, and the dose–response relationship was more evident for squamous cell carcinomas than for other histological types. An increase in risk of cancer of the lung with cumulative exposure to iron fumes was also found in this study. Exposures to iron fumes, chromium, nickel, lead, and benzo[*a*]pyrene were so strongly correlated with exposure to welding fumes that they could not be included in the same statistical model. To assess any potential confounding effect, additional analyses excluding workers with exposures to moderate or high levels of iron fumes, chromium, nickel, lead, and benzo[*a*]pyrene were performed. These exclusions did not markedly change the estimated risks associated with exposure to welding fumes. [The main strengths of this study were the large number of workers, the semi-quantitative assessment of exposure to welding fumes, and the availability of data on major potential confounders.]

Pukkala et al. (2009) linked individual records of 14.9 million people aged 30–64 years in the 1960, 1970, 1980/1981, and/or 1990 censuses in Denmark, Finland, Iceland, Norway, and Sweden to the 2.8 million incident cancer cases recorded in cancer registries for these people in a follow-up study until around 2005. The original national occupation codes were converted to a common classification with 53 occupational categories. As Danish welders were included in the broader group of mechanics workers, they were excluded from the analysis of welders which concerned 74 857 men and 2606 women. Results were reported for 49 cancer sites, some of them further divided according to subsite and histological type. Among men, elevated standardized incidence ratios were found for cancer of the lung (SIR, 1.33; 95% CI, 1.27–1.40), mesothelioma (SIR, 1.79; 95% CI, 1.44–2.20), cancer of the kidney (SIR, 1.25; 95% CI, 1.14–1.36), particularly cancer of the renal pelvis (SIR, 1.39; 95% CI, 1.05–1.80), and acute myeloid leukaemia (SIR, 1.23; 95% CI, 0.99–1.52). Thirty-six cases of ocular melanoma were observed (SIR, 1.07; 95% CI, 0.75-1.48). Among women the number of cases was small for most cancer sites, but an increased risk of cancer of the lung was also reported (SIR, 1.70;

95% CI, 1.10–2.51). No case of mesothelioma was observed among female welders (vs 0.3 expected). In men, elevated standardized incidence ratios were observed for all histological types of cancer of the lung, whereas in women increased risk was limited to histological types other than adenocarcinoma. No data on smoking habits were available, but an earlier study based on a previous follow-up of the Norwegian component of this study (Haldorsen et al., 2004) showed that, in male welders, indirect adjustment for smoking increased the cancer of the lung standardized incidence ratio from 1.31 to 1.48.

The Swedish component of this study overlaps several other record-linkage studies conducted in Sweden (Englund et al., 1982; Sjögren & Carstensen, 1986; McLaughlin et al., 1987; Alguacil et al., 2003). These studies were considered to be subsumed by the Pukkala et al. (2009) study, and are not discussed further.

Cancer risks associated with welding were evaluated by linking records on current job from the 1991 Canadian census of 1.1 million male workers with the Canadian Cancer Registry, and followed up until 2010 (MacLeod et al., 2017). Welders and occasional welders were compared with non-welders. Among welders, elevated risks were found for cancer of the lung (HR, 1.16; 95% CI, 1.03–1.31), mesothelioma (HR, 1.78; 95% CI, 1.01–3.18), cancer of the bladder (HR, 1.40; 95% CI, 1.15–1.70), and cancer of the kidney (HR, 1.30; 95% CI, 1.01–1.67). Five cases of ocular melanoma were observed (HR, 1.55; 95% CI, 0.64–3.76). The risks of cancer of the lung and mesothelioma were increased among occasional welders, but no excess risks were found for other cancer sites. Analyses by industry showed higher hazard ratios for cancer of the lung among welders in vehicle repair, shipbuilding and repair, and construction. Welders in construction also had an elevated risk of mesothelioma. Less than 5 mesothelioma cases were observed in other industries, and risk estimates were not reported. The risk of cancers of the bladder and kidney was increased for welders in all industry groups. By histological type of cancer of the lung, the strongest associations were found for carcinomas of the small cell and squamous cell. In analyses restricted to blue-collar workers, risk estimates were slightly attenuated for cancer of the lung and mesothelioma, and slightly increased for cancers of the bladder and kidney, and ocular melanoma.

Associations between occupation and cancer incidence were investigated in several studies which were part of the European Prospective Investigation into Cancer and Nutrition (EPIC). These studies assessed the risk of cancer of the lung (Veglia et al., 2007), cancer of the bladder (Pesch et al., 2013), lymphoma (Neasham et al., 2011), and leukaemia (Saberi Hosnijeh et al., 2013). Data on 52 a priori hazardous job titles were collected through standardized questionnaires. After adjustment for smoking, increased risks of cancer of the lung were associated with having ever worked as a welder (RR, 1.67; 95% CI, 1.20–2.30) or in the welding shop (RR, 1.55; 95% CI, 1.20–2.10). Elevated risks of cancer of the bladder were also found for welders (RR, 1.39; 95% CI, 0.85–2.27) and for those who worked in a welding shop (RR, 1.54; 95% CI, 1.01–2.34). There was no indication of an increased risk of leukaemia or lymphoma in welding occupations.

Wong et al. (2017) analysed the association between the incidence of cancer of the lung and occupation as metalworker (foundry and welders) in a cohort of frequent smokers who were enrolled in 33 centres across the USA, included in the National Lung Screening Trial (NLST). (Workers from both arms of the randomized control trial were combined in the analysis after 5–7 years of follow-up.) The adjusted hazard ratio of incidence of cancer of the lung for ever employed as a welder (excluding foundry workers and those who previously worked in high-risk occupations, such as asbestos workers) was 1.12 (95% CI, 0.91–1.37; 101 exposed cases). In analyses by cancer subtypes, the strongest association with welding was found for squamous cell carcinoma (adjusted HR, 1.91; 95% CI, 1.13–3.22; 11 cases) for those who had ever worked as a welder for 25 years or more, compared with workers without a history of metalwork (*P* for trend for employment duration, 0.003). [The strengths of this study included its prospective design, large number of cases, information on cancer of the lung subtypes, smoking habits, past exposure to asbestos and other carcinogens, and multivariate and sensitivity analyses. The study was limited by its short follow-up and lack of detailed exposure information for welding and occupational co-exposures.]

2.5 Case–control studies

2.5.1 Cancer of the lung

See Table 2.5 and Table 2.6

The Working Group identified more than 20 cancer of the lung case–control studies that reported on the association between welding-related occupations or exposure to welding fumes and cancer of the lung (Table 2.5). These include a pooled analysis of case–control studies (Kendzia et al., 2013) and a multicentre case–control study ('t Mannetje et al., 2012). The study by 't Mannetje et al. (2012) was included in the pooled analysis by Kendzia et al. (2013) for occupation as a welder; it is included in this review as it presents further analysis on exposure to welding fumes that was not presented in the analysis by Kendzia et al. (2013). We excluded studies that were superseded by subsequent publications using the same data (Jöckel et al., 1994; Richiardi et al. 2004; Brenner et al., 2010; Guida et al., 2011), but we retained studies (listed in Table 2.5) that were included in the pooling study if the original publication provided additional information. We also excluded studies whose job-exposure classification was so broad that it did not allow an assessment of the risk among welders specifically (Matos et al., 1998; Droste et al., 1999). Two studies conducted in different US coastal regions, with a reference category restricted to shipyard workers that consisted of non-welders likely exposed to asbestos (Blot et al., 1978, 1980), were also excluded. A case–control study that only included welders as cases and controls (Hull et al., 1989) and a case–case study (Paris et al., 2010) are not reported in Table 2.5 because they do not allow estimation of the risk of cancer of the lung among welders per se.

Most case–control studies reported elevated risks for workers employed as welders who reported welding as their job task, or workers who reported exposure to welding fumes (Breslow et al., 1954; Gerin et al., 1984; Buiatti et al., 1985; Kjuus et al., 1986; Lerchen et al., 1987; Schoenberg et al., 1987; Benhamou et al., 1988; Ronco et al., 1988; Zahm et al., 1989; Morabia et al., 1992; Jöckel et al., 1998; Pezzotto & Poletto, 1999; Gustavsson et al., 2000; Soskolne et al., 2007; Brenner et al., 2010; Corbin et al., 2011; Calvert et al., 2012; 't Mannetje et al., 2012; Tse et al., 2012; Vallières et al., 2012; Kendzia et al., 2013; Luqman et al., 2014; Matrat et al., 2016), but many of the observed associations were statistically non-significant [probably due to small sample sizes]. Two studies reported risk estimates close to unity (Pezzotto & Poletto, 1999; Vallières et al., 2012), but none reported odds ratios below unity for ever welding. Most studies were able to adjust for smoking, but adjustment for occupational co-exposures, in particular adjustment for asbestos exposure, was possible in fewer studies. Most studies report risk estimates only for men due to an insufficient number of women in this occupational group.

The SYNERGY pooling study with 15 483 male cases (568 of them being welders) and 18 388 male controls (427 of them being welders) is one of the most informative case–control studies on welding occupation and cancer of the lung (Kendzia et al., 2013). This analysis based on job title included adjustment for age, study centre, smoking, and occupations known to be associated with cancer of the lung (so-called List A jobs, many of them entailing exposure to asbestos) resulted in an adjusted odds ratio of 1.50 (95% CI, 1.20–1.88) for the longest held job as a welder. [The Working Group noted that this study was adjusted for asbestos exposure, but not specifically for welding-related asbestos exposure.] Jobs entailing occasional welding were also associated with elevated risks, but the risk estimates were smaller compared with that of regular welders. Compared with never welders, the odds ratios increased with duration of occupation as a welder from 1 to less than 3 years (OR, 1.14; 95% CI, 0.80–1.61), 3 to less than 10 years (OR, 1.46; 95% CI, 1.26–1.91), 10 to 25 years or less (OR, 1.38; 95% CI, 1.06–1.79), to more than 25 years (OR, 1.77; 95% CI, 1.31–2.39) (*P* for trend, < 0.0001). When stratified by histological type, odds ratios appeared to be strongest for carcinomas of the squamous cell and small cell and somewhat lower for adenocarcinomas. For never-smoker welders, the odds ratio for cancer of the lung was 2.04 (95% CI, 1.16–3.61). The overlap between this biggest pooling study (SYNERGY) (Kendzia et al., 2013), which includes 22 case–control studies conducted between 1985 and 2010, and the overlap among these other studies, is summarized in Table 2.6. Results are reported by the individual studies included in the SYNERGY pooled analysis when not reported in the pooled analysis. The study by Schoenberg et al. (1987) was not included in the pooled analysis by Kendzia et al. (2013).

Confounding by asbestos is a major concern in the assessment of the association between welding and cancer of the lung. Workers may be exposed to asbestos as a bystander in shipyards, but also from heat-protective clothing or blankets used to cover the weld to prevent abrupt cooling. Studies that controlled for asbestos, and additionally for smoking, are described in the following.

A study in the USA (Schoenberg et al. 1987) not included in the analysis by Kendzia et al. (2013) reported an odds ratio of 3.5 (95% CI, 1.8–6.6) in welders overall and an odds ratio of 2.5 (95% CI, 1.1–5.5) in welders not exposed to asbestos, where exposure was classified by an industrial hygienist.

In a German study, Jöckel et al. (1998) reported a detailed assessment of exposure to welding fumes and exposure to asbestos through a set of job-specific questionnaires (around 20 questions) and a supplementary questionnaire on welding. After adjustment for smoking and asbestos exposure, the odds ratio for ever being employed as a welder was 1.93 (95% CI, 1.03–3.61). In this study, ever being exposed to welding fumes and gases was associated with a slightly elevated risk (OR, 1.25; 95% CI, 0.94–1.65), but no dose–effect relationship was seen with cumulative exposure expressed in lifetime hours of welding after adjustment for smoking and asbestos. Odds ratios were reported of 1.38 (95% CI, 0.91–2.09) for less than 1000 hours, 1.14 (95% CI, 0.73–1.79) for 1000–6000 hours, and 1.10 (95% CI, 0.73–1.66) for more than 6000 hours. [There is partial overlap with the study by Kendzia et al. (2013).]

A Swedish study reported that 62% of welding entailed asbestos exposure, according to a detailed exposure assessment by an industrial hygienist (Gustavsson et al., 2000). Based on a self-completed questionnaire that gathered information on the lifetime occupational history, including company name and location, occupation, and work tasks for each job held for at least 1 year, an industrial hygienist performed a case-by-case classification of the intensity and probability (0, 20, 50, or 80%) of exposure to 7 agents. Intensity units for welding were assigned as 1, 5, and 15, where 15 units corresponded to full-time employment as a MMA welder. Cumulative exposure was calculated as the product of intensity, probability, and duration of exposure over all job periods. In analysing the dose–effect relationship with cumulative welding exposure, Gustavsson et al. (2000) did not observe

Table 2.5 Case–control studies on cancer of the lung and welding or exposure to welding fumes

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Breslow et al. (1954) California, USA 1949–1952	Cases: 518 histopathologically verified cases of lung cancer, 25 of them women Controls: 518 patients admitted to the hospital around the same time of the same age (within 5 yr), sex, and race for a condition other than cancer or a chest disease, chosen at random as a matched control for each case Exposure assessment method: questionnaire; job title	Non-welder or flame cutter (ref.)	508	[1]	None	Strengths: careful in-person interviews; assessment of welding as a task; non-consideration of short-term occupations Limitations: no age-adjustment; crude adjustment for smoking in five categories; smoking status missing in 5% of subjects; small number of welders
		Welder or flame cutter of > 5 yr	10	[10.2 (1.3–79.8)]		
		Non-welder (ref.)	479	[1]	None	
		Welders and sheet metal workers doing welding > 5 yr	14	[7.2 (1.6–31.7)]		
		Welders and sheet metal workers doing welding > 5 yr	14	[7.66 (1.36–43.23)]	Smoking	
Gerin et al. (1984) Montreal, Canada 1979–1982	Cases: 246 male cancer cases aged 35–70 yr from entire Montreal population at major hospitals for 12 tumour sites identified through hospital pathology department (1343 patients of whom 246 were diagnosed with lung cancer) Controls: 1241, 144 general-population healthy subjects and all cases of the remaining 11 tumour sites Exposure assessment method: questionnaire; individual expert assessment of exposure (focusing on Ni and Cr) based on job histories and a semi-structured probing section	Welders			Age, smoking, SES, ethnicity	Overlaps with the study of Vallières et al. (2012) and therefore also with the SYNERGY pooling study (Kendzia et al., 2013) Strengths: individual expert assessment; specific and detailed assessment of exposure to Ni and Cr Limitations: no control for asbestos or other occupational carcinogens but stratification by Ni exposure
		Non-welders (ref.)	227	1		
		All	12	2.4 (1.0–5.4)		
		With Ni exposure	10	3.3 (1.2–9.2)		
		Without Ni exposure	2	1.2 (0.1–9.4)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Buiatti et al. (1985) Florence, Italy 1981–1983	Cases: 376 histologically confirmed primary lung cancer cases admitted to the hospital serving as the referral centre for all lung cancers in the province of Florence (340 men and 36 women); patients not resident in the metropolitan area of Florence excluded Controls: 892 controls from the medical service of the same hospital, frequency-matched by sex, age (± 5 yr), date of admission (± 3 mo), and smoking status (7 categories) with discharge diagnoses other than lung cancer Exposure assessment method: questionnaire; personal interview including all jobs held for > 1 yr and an exposure checklist of 16 known/ suspected carcinogens	Men			Age, smoking, place of birth	Welding OR reported for men only Strengths: diligent consideration of possible selection biases possibly due to the hospital-based study design Limitations: small number; no adjustment for occupational co-exposure
		Never welder (ref.)	NR	1		
		Welder	7	2.8 (0.9–8.5)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Kjuus et al. (1986) SE Norway 1979–1983	Cases: 176 male incident lung cancer cases of age < 80 yr, admitted to the medical ward with the recent diagnosis of lung cancer Controls: 176 age-matched controls (± 5 yr) selected from the same ward; chronic obstructive lung diseases and conditions, implying physical or mental handicaps not eligible Exposure assessment method: questionnaire; subjects were interviewed at the bedside to obtain complete work history since 14 yr of age; job title and detailed information on relevant exposure factors were ascertained	Exposed for > 3 yr			Smoking	Results were similar for matched and unmatched analyses (accounting for age), but it is unclear whether this applies to welding Strengths: case–control status blinded in 90% of interviews; detailed work history included job descriptions; additional questionnaire on 17 agents and 5 specific work processes; diligent analysis including several sensitivity analyses to assess potential biases Limitations: small numbers; multiple comparisons and collinearity of exposures; age-adjustment not specifically mentioned for the analysis of welders
		Not exposed to welding (ref.)	148	1		
		Welding (all types)	28	1.9 (0.9–3.7)		
		Welding (SS, acid proof)	16	3.3 (1.2–9.3)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Lerchen et al. (1987) New Mexico, USA 1980–1982	Cases: 506 Hispanic white and other white residents aged 25–84 yr with primary lung cancer identified by the New Mexico Tumor Registry; 333 men and 173 women Controls: 771; ~1.5 controls per case frequency-matched by sex, ethnicity, and 10 yr age category, randomly selected from residential telephone numbers and (for subjects aged > 65 yr) from Medicare roster; 499 men and 272 women; response proportion 83% (2% next-of-kin) Exposure assessment method: questionnaire; personal interview including lifetime occupational history and self-reported agent exposures for each job held for > 6 mo from age 12 yr; exclusion of subjects with < 20 yr of employment	Male welders			Age, ethnicity, smoking	Welding risk estimates only reported for males Strengths: personal interview; jobs coded according to standard classifications and to an a priori list of high-risk occupations; stratification by industry (shipyard, other) Limitations: high proportion of next-of-kin in cases but not in controls
		Never employed as welders or in shipyard (ref.)	NR	1		
		All industries	19	3.2 (1.4–7.4)		
		Shipyard industry	6	2.2 (0.5–9.1)		
		Other industries	13	3.8 (1.4–10.7)		

Table 2.5 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Schoenberg et al. (1987) New Jersey, USA 1980–1981	Cases: 763 white male residents with incident histologically confirmed cancer of the lung trachea and bronchus, identified through reporting system based on pathology departments and cancer registry; response 70.4% Controls: 900; 1415 total general-population white male controls identified through death certificates and driver's license files (randomly), frequency matched by race, age, and area of residence; additionally matched for closest date of death for cases with next-of-kin respondent; deaths from lung cancer or respiratory disease excluded Exposure assessment method: questionnaire; personal interview including the history of all jobs held for > 3 mo since age 12 yr (job title, employer, type of business, tasks, materials handled, agent exposures); supplementary questions for shipbuilding workers; review of reported asbestos exposure by an industrial hygienist	Welders or burners	NR	3.8 (1.8–7.8)	Age, respondent type, smoking, study area, education, vegetable intake	Enrolment from six geographic areas, two of which had heavy concentrations of shipyard workers; reported ORs refer to welders in shipbuilding Strengths: verification of self-reported asbestos exposure by industrial hygienist blinded for case–control status; in-depth analysis of job tasks in shipbuilding; stratification by asbestos exposure (yes/no) Limitations: limited adjustment for smoking (never, cigars, or < 10 cigarettes/d, 10–29 cigarettes/d, ≥ 30 cigarettes/d, unknown) that lacked information on smoking duration
		Combined welders	33	3.5 (1.8–6.6)		
		Combined welders with no asbestos exposure	17	2.5 (1.1–5.5)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Benhamou et al. (1988) France 1976–1980	Cases: 1334 male cases with histologically confirmed lung cancer Controls: 2409; 1 or 2 hospital controls with nonsmoking related diseases were matched per case on sex, age at diagnosis (± 5 yr), hospital of admission, and interviewer Exposure assessment method: questionnaire; job history (jobs and duration of occupation); expert assessment of the data	Men only			Age, sex, hospital admission, interviewer, smoking	Analysis restricted to male nonsmokers or male exclusive cigarette smokers Strengths: complete job history Limitations: crude adjustment for smoking (smoking status, age at starting (2 categories), frequency (2 categories), duration (2 categories); no adjustment for occupational carcinogens
		Never welders or flame cutters (ref.)	1316	1		
		Welders and flame cutters	18	1.42 (0.79–2.88)		
Ronco et al. (1988) Turin, north Italy 1976–1980	Cases: 126 male residents who died from lung cancer from 1976–1980 Controls: 384, a random sample of men who died from other causes during 1976–1980, matched 3:1 by year of death and 10-yr age group (30–39 to 80–89); deaths from bladder and respiratory cancer excluded Exposure assessment method: questionnaire; next-of-kin interview at home (75–76%) or by telephone, including lifelong occupational history; job titles were coded blindly for case–control status according to ISCO and ICIT	Not welders (ref.)	120	1	Age, smoking, other occupations	Strengths: detailed adjustment for smoking and List A/B jobs[a] Limitations: cause of death obtained from local death registers; next-of-kin interview; exposure classification only based on job title
		Welders	6	2.93 (0.87–9.82)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Zahm et al. (1989) Missouri, USA 1980–1985	Cases: 4431 histologically confirmed lung cancer cases identified through Missouri Cancer Registry; all white men Controls: 11 326 cancer controls identified through Missouri Cancer Registry from white male residents excluding cancer of the lip, oral cavity, oesophagus, lung, bladder, ill-defined/unknown sites Exposure assessment method: smoking status and occupation at the time of diagnosis obtained from medical records; codable information available from 52% of cases and 45% of controls; among subjects with known occupations, smoking status was unknown in 15% of cases and 37% of controls	Welders and solderers vs. all other occupations				Strengths: large sample size; stratification by histological type Limitations: non-standardized assessment of occupation, only current job; crude adjustment for smoking (never, ex-, current, unknown smoker); a high proportion of missing smoking status; crude age adjustment (0–59, 60–69, >70 yr)
		All	29	1.2 (0.7–2.1)	Age, smoking	
		Adenocarcinoma	8	1.7 (0.7–3.8)		
		SCC	15	1.7 (0.9–3.3)		
		Small cell/oat cell	2	0.4 (0.1–1.8)		
		Other	4	0.8 (0.2–2.2)		
Morabia et al. (1992) Chicago, Birmingham, Detroit, Long Island, New York, Philadelphia, Pittsburgh, San Francisco (USA) 1980–1989	Cases: 1793 hospital-based male cases confirmed by histology Controls: 3228; 1 or 2 controls hospitalized for conditions not related to smoking, matched for age (5 yr), race (black/white), hospital, date of admission, and smoking history (never, ex-, current 1–19, current >20 cigarettes) Exposure assessment method: questionnaire	All other occupations; never worked as welder (ref.)	1548	1	Age, race, smoking, region	Strengths: personal interview Limitations: contradictory statement regarding inclusion/ exclusion of smoking-related disorders in controls; only usual job title and the list of 44 exposures was asked; questionnaire version changed twice during the study; reference group not precisely defined
		Welders and flame cutters	18	1.5 (0.8–2.7)		

Table 2.5 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Jöckel et al. (1998) West Germany 1988–1993	Cases: 1004; 839 men and 165 women from hospitals (females excluded from analysis) Controls: 1004 randomly drawn from a sample of mandatory residence registries, matched for region, sex, and age (±5 yr) Exposure assessment method: questionnaire; welding assessment for all workers reporting welding, regardless of job title, based on a welding-specific supplementary questionnaire; quantification of duration and frequency of each welding task; assessment of welding technique and type of metal; detailed quantitative assessment of asbestos exposure based on several job-specific questionnaires and a case-by-case expert assessment	Never exposed to welding fumes (ref.)	606	1	Smoking, asbestos	Included in the pooled SYNERGY analysis (Kendzia et al., 2013) Strengths: detailed supplementary questionnaire on welding independent of job title; quantitative assessment of welding hours; assessment of type of welding; assessment of type of metal; detailed adjustment for smoking and asbestos
		Welder or burner	47	1.93 (1.03–3.61)		
		Oxyacetylene welding	29	2.77 (1.20–6.38)		
		Welding fumes	233	1.25 (0.94–1.65)		
		Any type of welding: lifetime (h)				
		Never	608	1		
		< 1000	75	1.38 (0.91–2.09)		
		1000–6000	65	1.14 (0.73–1.79)		
		> 6000	91	1.10 (0.73–1.66)		
		Oxyacetylene welding: lifetime (h)				
		Never	668	1		
		< 1000	81	1.11 (0.75–1.63)		
		1000–6000	60	0.95 (0.60–1.51)		
		> 6000	30	1.46 (0.72–2.96)		
		> 10 000	NR	3.28		
		Gas-shielded welding	NR	3.6		
		Iron and steel welding	218	1.17 (0.87–1.56)		
		Welding in air/spacecraft industry				
		Never in industry/never welding (ref.)	587	1		
		Ever in industry/never welding	19	0.88 (0.42–1.84)		
		Never in industry/ever welding	197	1.14 (0.85–1.53)		
		Ever in industry/ever welding	36	2.29 (1.19–4.42)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Pezzotto and Poletto (1999) Rosario, Argentina 1992–1998	Cases: 367 men with newly diagnosed lung cancer from three hospitals of Rosario city; no refusals Controls: 576 selected from same hospitals, admitted for non-smoking related diseases; age-matched (±3 yr); no refusals Exposure assessment method: questionnaire; personal interview including lifetime occupational history (job title, tasks, employer, type of industry) for each job held for > 1 yr	Administrative staff (ref.)	98	1	Age, smoking	Strengths: stratification by histologic type; personal interviews Limitations: subjects with more than two different jobs were excluded; small number; diagnostic validity of case status not reported; method for job classification not standard and insufficiently described
		Welders	11	1.1 (0.4–3.1)		
		Welders (SCC)	7	2.9 (1–10.1)		
		Welders (adenocarcinoma)	3	0.7 (0.1–3.6)		

Table 2.5 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Gustavsson et al. (2000) Stockholm, Sweden 1985–1990	Cases: 1042 men aged 40–75 yr with diagnosis of lung cancer Controls: 2364 randomly selected from the general-population registry, frequency-matched to the cases in 5-yr groups and year of inclusion (1985–1990); additional matching for vital status to balance cases and controls with regard to being alive at data collection Exposure assessment method: expert judgement; postal questionnaire on lifetime occupational history, residential history since 1950, and smoking habits, as well as on some other potential risk factors for lung cancer; completion by telephone interview; occupational history supplemented by detailed questionnaire on work tasks, frequency, and location(s) for occupations involving potential exposure to motor exhaust; next-of-kin questionnaires for deceased cases/controls	Welding fumes: intensity of exposure			Age, year, smoking, exposure to Rn, NO_x	Included in the pooled SYNERGY analysis (Kendzia et al., 2013) Strengths: individual exposure assessment by industrial hygienist for intensity and probability of exposure to 7 agents for each job period, blinded for case–control status; prevalence of co-exposure to 6 agents reported (62% of welding entailed asbestos exposure, 100% metal dust, and 67% other combustion products [not engine exhaust]); detailed adjustment for smoking; additional adjustment for asbestos, combustion products, and diesel exhaust; stratification by exposure intensity, cumulative exposure, and duration Limitations: no in-person interviews, only telephone in case of missing items; exposure metric difficult to interpret
		Unexposed to welding fumes (ref.)	923	1		
		Low	41	1.67 (1.06–2.64)		
		Intermediate	25	1.17 (0.66–2.06)		
		High	33	1.42 (0.88–2.30)		
		Welding fumes: quartile of cumulative exposure			Age, year, smoking, residential, exposure to Rn, NO_x, diesel, combustion products, asbestos	
		1	29	1.41 (0.83–2.40)		
		2	34	1.38 (0.82–2.33)		
		3	27	0.79 (0.45–1.36)		
		4	29	0.84 (0.46–1.52)		
		Duration of exposure to welding fumes (yr)			Age, year, smoking, exposure to Rn, NO_x	
		0 (ref.)	NR	1		
		> 0–9	NR	1.70 (0.97–2.96)		
		10–29	NR	1.45 (0.96–2.20)		
		≥ 30	NR	1.25 (0.82–1.90)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Soskolne et al. (2007) Campania region, Italy 1988–1990	Cases: 168 patients with respiratory tract cancers (lung *n* = 111, larynx *n* = 35, nasal/pharynx *n* = 22) Controls: 247 unmatched patients without any respiratory, bladder, or oral cavity cancers, including patients having any other reason for hospitalization; hospital-based case-control study Exposure assessment method: expert judgement; occupational history; exposure to 20 agents classified by the industrial hygienist	No exposure to welding fumes (ref.)	NR	1	Age, smoking	Strengths: exposure assessment by the industrial hygienist, blinded for case–control status Limitations: variables on which the assessment of welding fume exposure was based not described; exposure assessment method not standardized; small number; crude adjustment for smoking (based on the pack-year variable: very low, low, medium, high)
		Exposure to welding fumes	13	3.91 (1.03–14.95)		
Brenner et al. (2010) Toronto, Canada 1997–2002	Cases: 445 incident cases of cancer of the trachea, bronchus, or lung diagnosed in men and women of age 20–84 yr from four major tertiary care hospitals in metropolitan Toronto Controls: 948 (425 population; 523 hospital); population-based controls were randomly sampled from property tax assessment files (*n* = 425), hospital-based controls were sampled from patients seen in the Mount Sinai Hospital Family Medicine Clinic (*n* = 523), frequency-matched with cases on sex and ethnicity Exposure assessment method: detailed questionnaire administered via interview either in person or over the telephone	Total study population			Age, sex, smoking, ethnicity, education	Included in the pooled SYNERGY analysis (Kendzia et al., 2013) Strengths: exposure category 'welding equipment' captures non-welding occupations with welding fume exposure; analysis of never smokers Limitations: frequency, intensity, duration of using 'welding equipment' is not stated
		Never worked/ exposed to welding equipment (ref.)	412	1		
		Exposure to welding equipment	33	1.7 (1–3)		
		Never smokers			Age, sex, education, ethnicity	
		Never worked/ exposed to welding equipment (ref.)	149	1		
		Exposure to welding equipment	7	3.4 (1.1–10.4)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Corbin et al. (2011) New Zealand 2007–2008	Cases: 457 incident cases of lung cancer aged 20–75 yr identified through the cancer registry; 53% of those eligible participated Controls: 792 controls selected from electoral rolls and recruited in two waves; frequency-matched for age distribution for lung cancer and three other cancer sites; 48% of those eligible participated Exposure assessment method: questionnaire; complete occupational history by telephone interview except for 432 controls who were interviewed face-to-face	Never employed as welder or flame cutter (ref.)	445	1	Age, sex, smoking, Maori ethnicity, SES	Included in the pooled SYNERGY analysis (Kendzia et al., 2013); no clear association with duration of employment (data not shown) Strengths: complete job history by interview; consideration of multiple comparisons by semi-Bayes adjustment Limitations: interviewing method not fully standardized; crude adjustment for smoking
		Welders and flame cutters (not SBA)	12	2.50 (0.86–7.25)		
		Welders and flame cutters (SBA)	12	1.92 (0.90–4.10)		
't Mannetje et al. (2012) UK, Romania, Hungary, Poland, Russian Federation, Slovakia, and Czech Republic 1998–2001	Cases: 2197 incident lung cancer (age, < 75 yr) Controls: 2295 frequency-matched on study area, sex, age (within 3 yr) and selected from hospital patients Exposure assessment method: expert judgement; face-to-face interview, and expert assessment of 70 agent exposures	Never exposed to welding fumes (ref.)	1615	1	Age, centre, education, asbestos, SiO_2, Ni, Cd, As, Cr, smoking	Included in the pooled SYNERGY analysis (Kendzia et al., 2013); *P* values for interaction between welding and co-exposures were 0.03 for asbestos and 0.54 for smoking Strengths: large multicentre study that used a common protocol; standardized exposure assessment methodology and high agreement in ratings between experts; results reported by welding activity; detailed questionnaire on welding activities Limitations: possible misclassification of assessed Cr exposure
		Ever worked as welder/flame cutter	NR	1.18 (0.84–1.66)		
		Ever worked as welder/flame cutter	NR	1.36 (1.00–1.86)	Age, centre, education, As, smoking	
		Weighted duration (h)			Age, centre, education, As, SiO_2, Cr, smoking	
		1–1680	173	1.03 (0.80–1.33)		
		1681–7000	180	1.05 (0.82–1.36)		
		> 7000	229	1.22 (0.94–1.58)		
		Trend test *P* value, 0.16				

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
’t Mannetje et al. (2012) (cont.)		Cumulative exposure (h)				
		1–2520	156	0.94 (0.73–1.21)		
		2521–28 900	222	1.27 (0.99–1.43)		
		> 28 900	204	1.09 (0.84–1.43)		
		Trend test *P* value, 0.19				
		Duration of arc welding (yr)				
		Only arc welding fumes	200	1.00 (0.78–1.29)		
		1–8	70	0.92 (0.63–1.34)		
		9–25	66	1.01 (0.68–1.49)		
		> 25	63	1.09 (0.72–1.65)		
		Duration of gas welding (yr)				
		Only gas welding fumes	87	1.25 (0.88–1.78)		
		1–8	42	1.12 (0.69–1.82)		
		9–25	25	1.37 (0.70–2.70)		
		> 25	20	1.46 (0.72–2.94)		
		Duration of gas and arc welding (yr)			Age, centre, education, As, Cd, SiO_2, Cr, smoking	
		Gas and arc welding fumes	296	1.13 (0.90–1.43)		
		1–8	65	1.08 (0.72–1.61)		
		9–25	90	0.92 (0.65–1.30)		
		> 25	141	1.38 (1.00–1.90)		
		Trend test *P* value, 0.01				
		Duration of exposure to welding fumes without chromium (yr)				
		Ever exposure	393	1.14 (0.95–1.36)		
		1–8	123	0.98 (0.74–1.30)		
		9–25	117	1.00 (0.75–1.34)		
		> 25	153	1.48 (1.11–1.97)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
't Mannetje et al. (2012) (cont.)		Duration of exposure to welding fumes with chromium (yr)				
		Ever exposed	190	1.34 (1.04–1.71)		
		1–8	54	1.47 (0.94–2.30)		
		9–25	64	1.28 (0.85–1.92)		
		> 25	71	1.27 (0.87–1.85)		
		Duration of welding (yr)			Age, centre, education, As, SiO_2, Cr, smoking	
		1–8	177	1.02 (0.79–1.31)		
		9–25	181	1.00 (0.77–1.30)		
		> 25	224	1.29 (1.00–1.67)		
		Trend test *P* value, 0.11				
Calvert et al. (2012) California, USA 1988–2007	Cases: 110 937 male lung cancer cases identified from cancer registries, aged 18–97 yr; year of diagnosis during 1988–2007 Controls: 322 699; up to 5 cancer controls from CCR database (prostate, colon, brain, kidney, testis, bone, joint, thyroid) were matched to each case on age (±5 yr), year of diagnosis (±5 yr), race, and ethnicity; occupational cancers excluded Exposure assessment method: demographic information as recorded in the CCR includes 'usual (i.e. longest-held) industry and occupation'; information was available in 48% of all registered cases; for job title coding the narrative was searched for 90 keywords related to construction work	Welders vs Construction workers other than welders			None	Morbidity ORs calculated by logistic regression Strengths: large sample size; stratification by histologic subtype Limitations: no lifestyle factors assessed; smoking status unknown; no standardized assessment of occupation or industry; women excluded
		All	216	2.16 (1.81–2.58)		
		NSCLC	132	2.10 (1.68–2.63)		
		Small cell/oat cell	29	2.72 (1.64–4.51)		
		Other, including mesothelioma	43	1.97 (1.33–2.93)		
		Adenocarcinoma	62	1.84 (1.33–2.53)		
		SCC	45	2.48 (1.66–3.72)		
		Large cell cancer	6	1.25 (0.47–3.36)		
		Unspecified NSCLC	19	2.95 (1.60–5.43)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Tse et al. (2012) China, Hong Kong SAR 2004–2006	Cases: 1208 male histologically confirmed lung cancer cases aged 35–79 yr Controls: 1069 male randomly selected referents living in the same districts as the cases, identified from telephone directories, frequency-matched to cases (5-yr age groups); excluding subjects with a history of physician-diagnosed cancer at any site (48% participation) Exposure assessment method: questionnaire; cases were interviewed within 3 mo of the diagnosis of lung cancer; occupational history of jobs held at least 1 yr (industry, job title, specific tasks performed, beginning/end dates of each job period); job titles/ industries coded according to ISCO/ISIC	Self-reported exposure welding fumes			Age, smoking, education, birth place, alcohol, Rn, lung disease history, cancer in family, consumption of meat	Included in the pooled SYNERGY analysis (Kendzia et al., 2013); after adjustment for asbestos the result did not change significantly [data not shown] Strengths: ISCO-/ ISIC-coding blinded for case–control status; self-reported exposures at least 1×/wk for at least 6 mo; adjustment for suspected occupational carcinogens; stratification by histologic type Limitations: self-reported agent exposure (checklist of suspected carcinogens: asbestos, Ar, Ni, Cr, tars, asphalts, SiO_2, painting, pesticides, diesel engine exhaust, cooking fumes, welding fumes, man-made mineral fibres); no elevated risk for asbestos observed (OR, 0.8)
		All combined	112	1.69 (1.11–2.58)		
		Adenocarcinoma	39	1.68 (1.00–2.81)		
		Self-reported welding fumes				
		Lung (squamous cell and small cell carcinoma)	39	2.29 (1.26–4.16)		
		Duration of exposure to welding fumes (yr)				
		All combined				
		1 to < 19	33	3.03 (1.30–7.07)		
		≥ 20	79	1.38 (0.86–2.24)		
		Adenocarcinoma				
		1 to < 19	16	3.82 (1.49–9.80)		
		≥ 20	23	1.18 (0.63–2.20)		
		Self-reported duration of exposure to welding fumes (yr)				
		Squamous cell and small cell carcinoma				
		1 to < 19	11	4.57 (1.34–15.54)		
		≥ 20	28	1.84 (0.93–3.64)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Vallières et al. (2012) Montreal, Canada Study I: 1979–1986; Study II: 1996–2001	Cases: 857 (Study I), 736 (Study II) men, incident, histologically confirmed lung tumours, aged 35–75 yr Controls: 1066 (Study I), 894 (Study II); population controls randomly selected from electoral rolls, matched by age and area of residence Exposure assessment method: expert judgement; supplementary questionnaire for welding, including questions on the type of gases used, metal welded, and h/wk and wk/yr of exposure	Arc welding fumes: exposure duration (yr)			Age, ethno-linguistic group, education, asbestos, respondent, study indicator, smoking	Included in the pooled SYNERGY analysis (Kendzia et al., 2013); pooled analysis of two case–control studies; women excluded because exposure prevalence was only 1%; indication of elevated risk only in never or low-frequency smokers Strengths: sophisticated exposure assessment methodology with welding exposure assessed in individuals by experts, beyond using job title only; population-based study; comprehensive confounder adjustment including asbestos; high response proportion (79–86% among cases and 69–72% among population controls) Limitations: possible exposure misclassification due to proxy interviews in 10–20% of controls and 30–40% of cases
		Not exposed (ref.)	1373	1		
		Any level	220	1.0 (0.8–1.2)		
		≤ 20	136	1.1 (0.8–1.4)		
		> 20	84	0.9 (0.6–1.3)		
		Gas welding fumes: exposure duration (yr)				
		Not exposed (ref.)	1369	1		
		Any level	224	1.1 (0.9–1.4)		
		≤ 20	136	1.3 (1.0–1.7)		
		> 20	88	0.9 (0.7–1.3)		
		Gas welding fumes exposure				
		SCC				
		Not exposed (ref.)	528	1		
		Any level	92	1.1 (0.8–1.5)		
		Substantial level	31	1 (0.6–1.6)		
		Lung (small cell/oat cell)				
		Not exposed (ref.)	237	1		
		Any level	47	1.3 (0.9–1.9)		
		Substantial level	19	1.3 (0.7–2.3)		
		Adenocarcinoma				
		Not exposed (ref.)	356	1		
		Any level	52	1 (0.7–1.4)		
		Substantial level	19	1 (0.6–1.8)		
		SCC				
		Not exposed (ref.)	523	1		
		Any level	97	1.1 (0.8–1.5)		
		Substantial level	33	1.3 (0.8–2.1)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Vallières et al. (2012) (cont.)		Small cell/oat cell				
		Not exposed (ref.)	245	1		
		Any level	39	0.9 (0.6–1.4)		
		Substantial level	13	0.9 (0.5–1.6)		
		Adenocarcinoma				
		Not exposed (ref.)	353	1		
		Any level	55	1 (0.7–1.4)		
		Substantial level	22	1.2 (0.7–2.1)		
		Never smokers/low-frequency smokers				
		Gas welding fumes not exposed (ref.)	91	1		
		Gas welding fumes, any level of exposure	33	2.8 (1.7–4.8)		
		Gas welding fumes, substantial level	15	4.3 (1.9–9.7)		
		Arc welding fumes, not exposed (ref.)	93	1		
		Arc welding fumes, any level of exposure	31	2.2 (1.3–3.7)		
		Arc welding fumes, substantial level	13	3.5 (1.6–7.8)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Kendzia et al. (2013) Europe, Canada, China, and New Zealand 1985–2010	Cases: 15 483; 568 cases had worked as welders Controls: 18 388; 427 controls had ever worked as welders Exposure assessment method: questionnaire; occupational and smoking histories were assessed in face-to-face interviews (81%); subjects considered exposed if job title was (1) 'welder' for ≥ 1 yr or (2) considered as potentially and occasionally involving welding activities	*All occupations*			Age, centre, smoking, List A job[a]	SYNERGY: pooled analysis of 16 studies; overlapping studies: Jöckel et al. (1998), Gustavsson et al. (2000), Richiardi et al. (2004), Brenner et al. (2010), Corbin et al. (2011), Guida et al. (2011), 't Mannetje et al. (2012), Vallières et al. (2012), Tse et al. (2012) Strengths: large pooled analysis that allowed stratification by duration of employment as a welder, histological type, smoking status (never smokers, pack-year), type of control, and blue-collar jobs; detailed adjustment for smoking (duration, intensity, duration of quitting, type of tobacco); adjustment for List A jobs[a]; restriction to blue-collar workers to indirectly and more tightly control for potential confounders Limitations: analysis based on job title with no information on welding process; no specific adjustment for asbestos exposure
		Never welding-related job (ref.)	12 921	1		
		Welder	568	1.44 (1.25–1.67)		
		Longest-held occupation	246	1.50 (1.20–1.88)		
		Ever blue-collar employee				
		Never welding-related job (ref.)	9796	1		
		Ever welder	568	1.33 (1.15–1.54)		
		Longest-held occupation	246	1.39 (1.11–1.73)		
		Ever welder				
		Never welding-related job (ref.)	12 921	1		
		Shipbuilding and repair	93	1.53 (1.06–2.21)		
		Construction and related building services	336	1.47 (1.22–1.78)		
		Manufacture of machines, equipment, appliances	352	1.40 (1.17–1.68)		
		Manufacture of motor vehicles and motor bikes	102	1.30 (0.94–1.80)		
		Repair of transport equipment	136	1.51 (1.12–2.03)		

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Kendzia et al. (2013) (cont.)		*Longest-held job*				
		Never welding-related job (ref.)	12 921	1		
		Shipbuilding and repair	33	1.53 (0.89–3.41)		
		Construction and related building services	46	1.33 (0.81–2.20)		
		Manufacture of machines, equipment, appliances	104	2.11 (1.45–3.08)		
		Manufacture of motor vehicles and motor bikes	12	0.62 (0.28–1.36)		
		Repair of transport equipment	16	1.10 (0.49–2.46)		
		All cases				
		Duration as welder (yr)				
		Never welding-related job (ref.)	12 921	1		
		1 to < 3	82	1.14 (0.80–1.61)		
		3 to < 10	171	1.46 (1.26–1.91)		
		10 to ≤ 25	167	1.38 (1.06–1.79)		
		> 25	148	1.77 (1.31–2.39)		
		Trend test *P* value, < 0.0001				

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Kendzia et al. (2013) (cont.)		*Adenocarcinoma*				
		Duration as welder (yr)				
		Never welding-related job (ref.)	3313	1		
		Ever welder	132	1.23 (0.99–1.53)		
		1 to < 3	18	0.84 (0.49–1.45)		
		3 to < 10	39	1.14 (0.77–1.68)		
		10 to ≤ 25	41	1.26 (0.85–1.87)		
		> 25	34	1.31 (0.85–2.02)		
		Trend test *P* value, 0.1041				
		SCC				
		Duration as welder (yr)				
		Never welding-related job (ref.)	5226	1		
		Ever welder	264	1.58 (1.32–1.89)		
		1 to < 3	41	1.38 (0.90–2.11)		
		3 to < 10	77	1.62 (1.16–2.25)		
		10 to ≤ 25	76	1.34 (0.97–1.85)		
		> 25	70	1.71 (1.19–2.46)		
		Trend test *P* value, 0.0002				
		Small cell/oat cell				
		Duration as welder (yr)				
		Never welding-related job (ref.)	1979	1		
		Ever welder	92	1.41 (1.09–1.82)		
		1 to < 3	14	1.25 (0.67–2.35)		
		3 to < 10	32	1.49 (0.96–2.32)		
		10 to ≤ 25	28	1.30 (0.82–2.07)		
		> 25	18	1.20 (0.69–2.11)		
		Trend test *P* value, 0.1311				

Table 2.5 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Kendzia et al. (2013) (cont.)		*All cases*				
		Never welding-related job (ref.)	12 921	1		
		Never-smoker welders	15	2.34 (1.31–4.17)		
		Adenocarcinoma				
		Never welding-related job (ref.)	3313	1		
		Never-smoker welders	6	1.89 (0.79–4.52)		
		SCC				
		Never welding-related job (ref.)	5226	1		
		Never-smoker welders	4	3.01 (1.07–8.49)		
		Small cell/oat cell				
		Never welding-related job (ref.)	1979	1		
		Never-smoker welders	2	4.45 (1.03–19.20)		
		Welding–smoking interaction				
		Never-smoker–never welding-related job (ref.)	439	1		
		Never-smoker welders	15	2.04 (1.16–3.61)		
		Trend test *P* value, 0.222				

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Luqman et al. (2014) Pakistan 2010–2013	Cases: 400 histologically confirmed cases of lung cancer from different hospitals Controls: 800 hospital controls with no cancer or chronic respiratory disease Exposure assessment method: questionnaire	Not exposed to welding fumes (ref.)	8	1	None	Strengths: the first epidemiological study on welding and lung cancer from Pakistan Limitations: a risk estimate for 'welding fumes' is presented even though there was no quantitative exposure assessment; it is unclear if there was multivariable adjustment (e.g. smoking, asbestos) in the statistical models
		Welding fumes	10	2.5 (1–6.5)		
Matrat et al. (2016) France 2001–2007	Cases: 2276 population-based histologically confirmed, incident primary lung cancer cases in men aged 18–75 yr, identified through 10 of 11 cancer registries Controls: 2780 population controls from the same administrative department using random digit dialling, frequency-matched with cases for sex (only men) and age; additional statistical analysis on SES also performed Exposure assessment method: questionnaire; face-to-face interviews using standardized questionnaire, recording details of each occupation lasting ≥ 1 mo, with 20 job-specific questionnaires; asbestos exposure assessed by both a task-exposure matrix and a job-exposure matrix	No welding (ref.)	1629	1	Age, department, smoking, asbestos, number of jobs	ICARE study. Complements study by Guida et al. (2011) and presents additional analyses beyond Kendzia et al. (2013). Data on soldering and brazing also available in the study Strengths: detailed questionnaire on welding; quantification of welding exposure and assessment of the type of welding; consideration of co-exposures; adjustment for asbestos exposure Limitations: each welder had worked with each type of metal, preventing isolation of groups that had welded a unique type of metal
		Regular welders	100	1.66 (1.11–2.49)		
		Frequency of welding (%)				
		Regular welders, ≤ 5	8	1.17 (0.31–4.51)		
		> 5	92	1.67 (1.10–2.54)		
		Trend test *P* value, 0.19				
		Duration (yr)				
		Regular welders, ≤ 10	34	1.53 (0.91–2.55)		
		> 10	58	1.96 (0.98–3.92)		
		Trend test *P* value, 0.02				

Table 2.5 (continued)

Reference, location, enrolment/ follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Matrat et al. (2016) (cont.)		Regular ever welders: type of welding				
		No welding (ref.)	1629	1		
		Gas	64	1.98 (1.20–3.29)		
		Arc	65	1.99 (1.21–3.26)		
		Spot	38	1.35 (0.72–2.53)		
		Other	17	1.80 (0.72–4.51)		
		Regular welders, by covering and preparation of surfaces to be welded				
		No welding (ref.)	1629	1		
		Presence of grease or paint on the pieces	53	1.98 (1.15–3.43)		
		Cleaning with mechanical preparation only	25	0.97 (0.48–1.97)		
		Cleaning with chemical or mechanical preparation	26	2.79 (1.35–5.77)		
		Regular and occasional welders, chemicals used to clean the surface to be welded				
		Never used any chemical (ref.)	180	1		
		Paint stripper	33	1.46 (0.76–2.83)		
		Trichloroethylene	59	1.30 (0.77–2.20)		
		Gasoline	41	1.92 (1.01–3.65)		
		White spirit	34	1.69 (0.86–3.31)		
		Acid	26	2.54 (1.05–6.13)		

[a] List A/B jobs are defined as high-risk occupations known to be associated with lung cancer, many of which entail asbestos exposure

As, arsenic; CCR, Californian Cancer Registry; Cd, cadmium; CI, confidence interval; Cr, chromium; d, day(s); h, hour(s); ICIT, Index de la Classification Type; ISCO, International Standard Classification of Occupations; ISIC, International Standard Industrial Classification; mo, month(s); NO_x, nitrogen oxides; Ni, nickel; NR, not reported; NSCLC, non small cell lung carcinoma; OR, odds ratio; Rn, radon; SAR, Special Administrative Region; SBA, steel beam assembly; SCC, squamous cell carcinoma; SES, socioeconomic status; SiO_2, silicon dioxide; SS, stainless steel; wk, week(s); yr, year(s)

Table 2.6 Studies included in the SYNERGY pooling study

Study name	Country	Period	Overlapping studies
AUT	Germany	1990–1995	
HdA	Germany	1988–1993	Jöckel et al. (1998)
EAGLE	Italy	2002–2005	
TURIN/VENETO	Italy	1990–1994	Richiardi et al. (2004)
ROME	Italy	1993–1996	
LUCA	France	1989–1992	
PARIS	France	1988–1992	
ICARE	France	2001–2007	Guida et al. (2011); Matrat et al. (2016)
CAPUA	Spain	2000–2010	
MORGEN	Netherlands	1993–1997	
INCO	Czech Republic	1999–2002	’t Mannetje et al. (2012)
INCO	Hungary	1998–2001	’t Mannetje et al. (2012)
INCO	Poland	1998–2002	’t Mannetje et al. (2012)
INCO	Slovakia	1998–2002	’t Mannetje et al. (2012)
INCO	Romania	1998–2002	’t Mannetje et al. (2012)
INCO	Russian Federation	1998–2001	’t Mannetje et al. (2012)
INCO (LLP)	United Kingdom	1998–2005	’t Mannetje et al. (2012)
LUCAS	Sweden	1985–1990	Gustavsson et al. (2000)
OCANZ	New Zealand	2003–2009	Corbin et al. (2011)
MONTREAL	Canada	1996–2002	Vallières et al. (2012) only study II included; Gerin et al. (1984) (recruitment 1979–82) not included; Vallières et al. (2012) includes Gerin et al. (1984)
TORONTO	Canada	1997–2002	Brenner et al. (2010)
HONG KONG	China	2003–2007	Tse et al. 2012

Compiled by the Working Group using information from Kendzia et al. (2013)

an elevated risk in the upper two quartiles of welding exposure after adjustment for asbestos and other potential confounders. Odds ratios of 1.41 (95% CI, 0.83–2.40), 1.38 (95% CI, 0.82–2.33), 0.79 (95% CI, 0.45–1.36), and 0.84 (95% CI, 0.46–1.52) were reported for quartiles 1, 2, 3, and 4, respectively. [The quality of exposure information in this study was limited due to the fact that it included mainly next-of-kin information (93% in cases, 19% in population controls, and 89% in mortality-matched controls) and was based on a mailed self-completed questionnaire. There is partial overlap with the study of Kendzia et al. (2013).]

Asbestos exposure was also assessed in detail in the multicentre study by ’t Mannetje et al. (2012) conducted in eastern Europe and the UK, in which occupational histories were collected by face-to-face interviews. A total of 70 agent exposures were assessed by experts for each job regarding the expert’s confidence in the presence of the exposure (possible, probable, certain), the percentage of working time exposed (1–5%, > 5–30%, > 30%), and the intensity (low, medium, high) according to a common protocol; high agreement was observed ($\kappa = 0.9$) between experts in the assessment of exposure to welding fumes. Analyses were reported adjusted for asbestos, smoking, and other occupational exposures such as chromium and nickel. In this study, the odds ratio for ever working as a welder or flame–cutter, adjusted for asbestos, silica, and metal exposure (e.g. Cr), not assessed from welding and smoking, was 1.36 (95% CI, 1.00–1.86). The similarly adjusted odds ratio for ever exposure to welding fumes was 1.18

(95% CI, 0.84–1.66). The odds ratios with lifetime exposure expressed in cumulative welding hours for 1–2520 hours, 2521–28 900 hours, and more than 28 900 hours were 0.94 (95% CI, 0.73–1.21), 1.27 (95% CI, 0.99–1.43), and 1.09 (95% CI, 0.84–1.43), respectively (*P* for trend, 0.19). This metric was calculated as the product of total hours exposed and intensity level (weights 1, 6, and 20). The study authors also calculated a weighted duration by multiplying the number of years (each year equivalent to 2000 hours) by the frequency (0.03, 0.175, and 0.65 for low, medium, and high, respectively) of exposure. This metric resulted in adjusted odds ratios for 1–1680 hours, 1681–7000 hours, and more than 7000 hours of 1.03 (95% CI, 0.80–1.33), 1.05 (95% CI, 0.82–1.36), and 1.22 (95% CI, 0.94–1.58), respectively (*P* for trend, 0.16). Categorized by years of exposure to both gas and arc welding fumes, adjusted odds ratios for 1–8 years, 9–25 years, and more than 25 years of 1.08 (95% CI, 0.72–1.61), 0.92 (95% CI, 0.65–1.30), and 1.38 (95% CI, 1.00–1.90), respectively, were observed (*P* for trend, 0.01). [The Working Group noted the partial overlap with the study by Kendzia et al. (2013).]

Vallières et al. (2012) conducted a study in Montreal, Canada, using a protocol similar to that of ’t Mannetje et al. (2012). Exposure to asbestos and welding fumes was assessed in great detail by industrial hygienists. No elevated risks and no duration–effect relationship were observed for arc welding (OR, 1.0; 95% CI, 0.8–1.2) or gas welding (OR, 1.1; 95% CI, 0.9–1.4) for any level of exposure after adjustment for asbestos, smoking, and other confounders. In an analysis restricted to never and low-frequency smokers, statistically significant elevated risks were observed for any level of exposure to both gas and arc welding fumes, assessed separately. No association was observed among smokers of medium and high frequency. [The Working Group noted the partial overlap with the study by Kendzia et al. (2013).]

Matrat et al. (2016) adjusted for asbestos exposure in a recent case–control study conducted in France. Exposure was based on information gathered by face-to-face interviews that included a lifelong occupational history, including job periods, and 20 job-specific questionnaires. A detailed 4-page supplementary questionnaire was used if a respondent declared that more than 5% of his working time was devoted to welding, brazing, or gas cutting. Regular welders were defined as participants who reported being employed as a welder for at least one job period. From detailed information on asbestos exposure, a cumulative exposure index was calculated as the product of the duration of the corresponding job task, the probability of exposure, and the intensity of exposure. This index was categorized into four classes and then used for adjustment. The smoking- and asbestos-adjusted odds ratio for regular welders (which corresponds to ever being employed as a welder) compared with non-welders was 1.66 (95% CI, 1.11–2.49). The adjusted odds ratios for being a regular welder for less than 10 years was 1.53 (95% CI, 0.91–2.55) and for 10 years or more was 1.96 (95% CI, 0.98–3.92) (*P* for trend, 0.02). [The Working Group noted the partial overlap with the study by Kendzia et al. (2013).]

Several studies assessed the risks of cancer of the lung in relation to different welding processes (gas [oxyacetylene] welding, electric arc welding, gas-shielded welding [a type of arc welding preferably used on SS]) as well as type of metal (MS vs SS [chromium–nickel alloy]). See Section 1 for further details on welding types and processes.

Gerin et al. (1984) observed a higher odds ratio in welders with exposure to nickel (OR, 3.3; 95% CI, 1.2–9.2) than in welders without nickel exposure (OR, 1.2; 95% CI, 0.1–9.4). Kjuus et al. (1986) observed a difference in risk by material welded with an odds ratio of 3.3 (96% CI, 1.2–9.3) for 3 years or more of welding of SS and an odds ratio of 1.9 (95% CI, 0.9–3.7) for welding of any type of steel. In a case–control study restricted to welders, Hull et al. (1989) did not consistently show higher risks due to welding of high-alloy steel/SS as compared with MS. [This study, conducted among welders only, was difficult to interpret due to a contaminated reference group.] The multicentre study by ’t Mannetje et al. (2012) reported odds ratios for more than 25 years duration of exposure to welding fumes without chromium (OR, 1.48; 95% CI, 1.11–1.97) and containing chromium (OR, 1.27; 95% CI, 0.87–1.85). Although both Jöckel et al. (1998) and Matrat et al. (2016) collected information on the welding of SS in a welder-specific questionnaire, neither studies reported a corresponding risk estimate because most participants reported using different welding processes and on different metals. [These results indicate that any observed risks are not fully explained by exposure to high concentrations of nickel or chromium in the welded steel.]

Investigating the varying exposures to welding fumes between different types of welding, Jöckel et al. (1998) observed the higher odds ratio for gas welding in the highest category of cumulative exposure (6000 hours) (OR, 1.46; 95% CI, 0.72–2.96) in comparison with electric arc welding . Regular oxyacetylene welding for at least 2 hours per day, for 2 days per week for a minimum of 3 years, was associated with an odds ratio of 2.77 (95% CI, 1.20–6.38) in this study. ’t Mannetje et al. (2012) also observed higher odds ratios for only gas welding for more than 25 years duration (OR, 1.46; 95% CI, 0.72–2.94) than for only arc welding for more than 25 years duration (OR, 1.09; 95% CI, 0.72–1.65). Matrat et al. (2016) also reported that gas welding exclusively was associated with a higher risk of cancer of the lung than arc welding. The study by Vallières et al. (2012) observed an association between welding and cancer of the lung mainly in nonsmokers and low-frequency smokers; odds ratios for gas as compared to arc welding (OR for substantial level of exposure to welding fumes in non-/low smokers were 4.3 (95% CI, 1.9–9.7) for gas welding and 3.5 (95% CI, 1.6–7.8), for arc welding) respectively.

Welding often takes place under particular circumstances, especially in maintenance and repair work when materials are coated or need to be cleaned before welding. When exploring the role of substances covering the metal surface to be welded and that of the cleaning procedure, Matrat et al. (2016) observed an increased risk among regular welders for the presence of grease or paint on the welded pieces (OR, 1.98; 95% CI, 1.15–3.43). They also reported an increased risk for cleaning with chemical or mechanical preparation (OR, 2.79; 95% CI, 1.35–5.77), but not for cleaning with mechanical preparation only (OR, 0.97; 95% CI, 0.48–1.97).

2.5.2 Cancer of the kidney

See Table 2.7

Eight case–control studies that reported on the association between cancer of the kidney and welding-related occupations or exposure to welding fumes were identified (Magnani et al., 1987; Siemiatycki, 1991; Keller & Howe, 1993; McCredie & Stewart, 1993; Mandel et al., 1995; Pesch et al., 2000; Mattioli et al., 2002; Brüning et al., 2003). [An additional report was identified (Parent et al., 2000) but not included in this review, as it covered the same study population as reported on in Siemiatycki (1991).]

Five of these studies reported odds ratios of 1.10–1.76 for welding occupations (Siemiatycki, 1991; Keller & Howe, 1993; McCredie & Stewart, 1993; Mandel et al., 1995; Brüning et al., 2003), none of which reached statistical significance.

Five of the eight case–control studies assessed exposure to welding fumes using a JEM or by expert assessment. A study from Canada (Siemiatycki, 1991), which included patients diagnosed with cancers other than kidney as controls, reported an odds ratio of 0.8 (95% CI, 0.5–1.3) for both exposure to arc welding fumes and exposure to gas welding fumes as assessed by experts, based on 17 and 16 exposed cases, respectively. [The Working Group noted that the exposed cases and controls were likely the same for arc and gas welding fumes.] Odds ratios did not increase when analyses were restricted to "substantial" exposure to the two types of welding fumes. A study from northern Italy (Mattioli et al., 2002) reported an odds ratio of 5.67 (95% CI, 0.78–41.31) for expert-assessed exposure to welding fumes based on 8 exposed cases. Two studies used a JEM to assess exposure to welding fumes. A study from Germany (Pesch et al., 2000) reported an odds ratio of 1.3 (95% CI, 1.0–1.8) for exposure to medium levels of welding fumes based on 56 exposed cases, while exposure to high levels was associated with an odds ratio of 1.1 (95% CI, 0.8–1.6). A later study from Germany (Brüning et al., 2003) using a JEM to assess exposure to welding fumes reported an odds ratio of 2.73 (95% CI, 1.06–7.06) for low levels based on 9 exposed cases and 3.10 (95% CI, 1.37–7.02) for high levels based on 13 exposed cases. [The Working Group noted that the focus of this report was TCE as a risk factor for cancer of the renal pelvis; there was no adjustment for exposure to TCE however, so it is unclear how much of the elevated odds ratio for welding fumes is due to uncontrolled confounding by exposure to TCE.]

2.5.3 Cancer of the haematopoietic system

See Table 2.8 (web only; available at: http://publications.iarc.fr/569)

(a) Leukaemia

The Working Group identified nine case–control studies of leukaemia in adults that reported estimates of increased risk for welding-related jobs (Stern et al., 1986; Preston-Martin & Peters, 1988; Keller & Howe, 1993; Bethwaite et al., 2001; Costantini et al., 2001; Oppenheimer & Preston-Martin, 2002; Adegoke et al., 2003; Wong et al., 2010; Luckhaupt et al., 2012). Several studies reported risk estimates for a combined group of leukaemias (Keller & Howe, 1993; Costantini et al., 2001; Adegoke et al., 2003; Luckhaupt et al., 2012), reporting odds ratios ranging from 0.90 to 2.25; these were based on relatively small numbers of exposed cases however, and none reached statistical significance. [The Working Group noted that chronic lymphocytic leukaemia (CLL) was included in the definition of leukaemia by Adegoke et al. (2003) and Luckhaupt et al. (2012), not included in the definition by Costantini et al. (2001), and it was not clear whether it was included in the definition by Keller & Howe (1993).]

(i) Leukaemia subtypes

Several studies reported risk estimates for myeloid leukaemia or subtypes of myeloid leukaemia. An exceptionally high odds ratio was reported in 1988 for a chronic myeloid leukaemia case–control study based in Los Angeles County (Preston-Martin & Peters, 1988). A total of 22 of the 130 cases in the study had been employed as welders (compared with 4 of the 130 controls), yielding an adjusted odds ratio of 25.4 (95% CI, 2.78–232.54). A later study from California reported an odds ratio of 0.86 (95% CI, 0.29–2.53) for chronic myeloid leukaemia (Luckhaupt et al., 2012) related to welding in the construction industry. Three studies reported on acute myeloid leukaemia (AML), all with odds ratios above unity but none reaching statistical significance (Oppenheimer & Preston-Martin, 2002; Wong et al., 2010; Luckhaupt et al., 2012). A study from New Zealand on AML and acute lymphoblastic leukaemia (ALL) combined reported an odds ratio of 2.79 (95% CI, 1.2–6.8) for welders/flame-cutters; separate odds ratios for AML and ALL were not presented, however. [The Working Group assumed that the majority of the study population would be AML, but numbers were not provided.]

None of the leukaemia case–control studies reported associations with exposure to welding fumes, and none reported duration–response associations.

Table 2.7 Case–control studies on cancer of the kidney and welding or exposure to welding fumes

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/ deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Magnani et al. (1987) UK (three English counties) 1959–1963/ 1965–1979	Cases: 147 deaths at age 18–54 yr, identified from death certificates Controls: 556 deaths in the same year from other causes matched for sex, county of residence, age; identified from death certificates Exposure assessment method: expert judgement; Pannett JEM, based on job title on death certificate	Welding fumes	NR	1.8 (0.7–2.2)	Sex, county, age at death	Strengths: JEM assessed exposure Limitations: small size; occupational data obtained from death certificates; occupational histories available more often for cases than for controls; no adjustment for smoking
Siemiatycki (1991) Canada, Montreal 1979–1985	Cases: 177 male residents of the Montreal metropolitan area with histologically confirmed incident kidney cancer, age 35–70 yr Controls: 2481 study subjects with other cancers Exposure assessment method: expert judgement	Arc welding fumes (any)	17	0.8 (0.5–1.3)	Age, family income, cigarette index, ethnic origin	Strengths: expert assessment based on full occupational history and detailed task descriptions, and job-specific questionnaires Limitations: small size; use of cancer controls
		Arc welding fumes (substantial)	6	1.0 (0.5–1.9)		
		Gas welding fumes (any)	16	0.8 (0.5–1.3)		
		Gas welding fumes (substantial)	5	0.7 (0.3–1.5)		
		Welding fumes	6	1.5 (0.7–3.1)		
Keller & Howe (1993) USA, Illinois 1986–1989	Cases: 1372 newly diagnosed male kidney cancer cases reported in Illinois hospitals (hospital based) Controls: 4326 random sample of approximately 10% of all other cancers Exposure assessment method: questionnaire; job title recorded at cancer registration	Male welder	NR	1.75 (0.96–3.18)	Age, history of tobacco use	This study reports on multiple cancer sites Strengths: large size Limitations: only job at cancer registration is recorded; only welders within the construction industry are selected in the exposed group; unclear how many welders (outside of the construction industry) are categorized as unexposed; cancer controls

Table 2.7 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
McCredie & Stewart (1993) Australia, NSW 1989–1990	Cases: 636 age 20–79 yr at diagnosis (population based); 489 RCC and 147 renal pelvic cancer cases Controls: 523 electoral rolls, randomly selected (population based) Exposure assessment method: questionnaire, face-to-face interviews; employment in certain industries and occupations, exposure to chemicals with suspected associations with kidney cancer; question on employment as welder (among other)	Welder	40	1.37 (0.80–2.34)	Age, sex, method of interview	Strengths: large size, population controls, specific questions on welding Limitations: no specific assessment of exposure to welding fumes
		Welder	8	1.66 (0.68–4.03)		
		Welder (RCC and urinary pelvis)	48	1.50 (0.27–8.16)		
Mandel et al. (1995) Australia, Denmark, Germany, Sweden, USA 1989–1991	Cases: 1732 cases of incident renal cell adenocarcinomas, age 20–79 yr, confirmed by histopathology or cytology Controls: 2309 population controls Exposure assessment method: questionnaire; Germany collected full occupational histories, other centres asked specific occupations and welding industry	Welder	77	1.1 (0.8–1.6)	Age, tobacco, BMI, education, study centre	Strengths: large size Limitations: no results by duration
Pesch et al. (2000) Germany 1991–1995	Cases: 935; 570 men and 365 women with no age limit (population based) Controls: 4298 population; 2650 men and 1648 women (population based) Exposure assessment method: expert judgement; British JEM	Level of exposure to welding fumes for men only			Age, study centre, smoking, region	ORs for 'welding, soldering, milling' were also reported, but this occupational group was considered too broad Strengths: large size, welding fumes assessed through JEM Limitations: exposure assessment beyond that provided by use of a JEM not provided
		Medium	56	1.3 (1–1.8)		
		High	46	1.1 (0.8–1.6)		
		Substantial	16	1.2 (0.7–2.1)		

Table 2.7 (continued)

Reference, location, enrolment/follow-up period	Population size, description, exposure assessment method	Exposure category or level	Exposed cases/deaths	Risk estimate (95% CI)	Covariates controlled	Comments
Mattioli et al. (2002) North Italy 1986–1994	Cases: 249 histologically confirmed RCC cases (hospital based) Controls: 238 hospital controls with non-RCC diagnosis (hospital-based) Exposure assessment method: questionnaire; occupational history, plus expert assessment for selected exposures including welding fumes	Men only: welding fumes	8	5.67 (0.78–41.31)	Age, birthplace, residence, smoking	Strengths: expert assessment Limitations: small size, small number of exposed cases
Brüning et al. (2003) Arnsberg, Germany 1999–2000	Cases: 134 incident histologically confirmed RCC cases with nephrectomy 1992–2000 Controls: 401 hospital controls (no dementia, no cancer), 3:1 frequency-matched by sex and age (5 yr) Exposure assessment method: questionnaire; job title, plus Pannett JEM; next of kin interviews included	Welding job	10	1.76 (0.75–4.11)	Age, sex, smoking	TCE was a risk factor in this study, but ORs for welding were not adjusted for TCE Strengths: although the study is small, the prevalence of welding is substantial Limitations: small size
		Level of exposure to welding				
		Low	9	2.73 (1.06–7.06)		
		High	13	3.10 (1.37–7.02)		

BMI, body mass index; CI, confidence interval; JEM, job-exposure matrix; NR, not reported; OR, odds ratio; RCC, renal cell carcinoma; TCE, trichloroethylene; UUT, upper urinary tract; yr, year(s)

(b) Non-Hodgkin lymphoma

The Working Group identified 13 NHL case–control studies (Persson et al., 1989; Siemiatycki, 1991; Persson et al., 1993; Figgs et al., 1995; Costantini et al., 1998; Mao et al., 2000; Costantini et al., 2001; Fabbro-Peray et al., 2001; Zheng et al., 2002; Band et al., 2004; Dryver et al., 2004; Karunanayake et al., 2008; 't Mannetje et al., 2008) that reported on the association between NHL and welding-related occupations or exposure to welding fumes, and one large pooled case–control study ('t Mannetje et al., 2016).

Reported risk estimates for occupation as a welder were close to unity for 4 out of the 13 studies and above unity for 9 individual studies, 4 of which reported statistically significant increased risk estimates for all NHL (Persson et al., 1993; Zheng et al., 2002; Dryver et al., 2004) or specific NHL subtypes (Band et al., 2004). With the exception of the study by Dryver et al. (2004), these odds ratios were based on relatively small numbers of exposed cases. The largest NHL case–control study reporting on welding occupation was a pooled analysis of 10 case–control studies from Australia, Canada, Europe, and the USA ('t Mannetje et al., 2016). Ever employment in a welding-related occupation was associated with an odds ratio of 1.03 (95% CI, 0.83–1.27) based on 174 exposed cases. An odds ratio of 1.01 (95% CI, 0.69–1.48) was observed for those who had held a welding-related job for more than 10 years (53 exposed cases). Analyses were conducted for the main NHL subtypes (diffuse large B-cell lymphoma (DLBCL), follicular lymphoma, and small lymphocytic lymphoma (SLL/CLL), showing an elevated odds ratio only for DLBCL (OR, 1.31; 95% CI, 0.99–1.74). Compared with never welders, those who had worked for more than 10 years in a welding-related job had an increased risk of DLBCL (OR, 1.20; 95% CI, 0.70–2.05) and of follicular lymphoma (OR, 1.25; 95% CI, 0.63–2.49).

Three NHL case–control studies assessed exposure to welding fumes or frequency of welding tasks. A study from Canada (Siemiatycki, 1991), using patients diagnosed with cancers other than NHL as controls and expert assessment for exposure to welding fumes, reported an odds ratio of 0.8 (95% CI, 0.6–1.2) for arc welding fumes and 0.8 (95% CI, 0.5–1.2) for gas welding fumes. [The Working Group noted that the odds ratios on the same numbers of exposed cases were very similar, suggesting that most exposed cases and controls were assessed by the experts as exposed to both gas welding and arc welding fumes.] A study from Sweden (Dryver et al., 2004) reported odds ratios for both welding occupation and exposure to welding fumes (self-reported). The risk for welding was elevated (OR, 1.41; 95% CI, 1.01–1.99), while the risk for exposure to welding fumes was not (OR, 0.98; 95% CI, 0.73–1.30). [The Working Group noted that more people reported exposure to welding fumes than occupation as a welder. The group exposed to welding fumes was therefore likely to include many that only performed occasional welding or worked in areas where welding was conducted.] A study from France (Fabbro-Peray et al., 2001) assessed the frequency of welding-related tasks (self-reported), reporting an odds ratio of 1.7 (95% CI, 0.8–3.4) for those who welded often and one of 2.6 (95% CI, 1.4–5.1) for those who welded daily. Associations remained after adjusting for benzene exposure, which was found to be a risk factor in this study.

(c) Multiple myeloma

The Working Group identified five case–control studies of multiple myeloma in adults that reported risk estimates for welding-related jobs (Eriksson & Karlsson, 1992; Heineman et al., 1992; Demers et al., 1993; Costantini et al., 2001; Baris et al., 2004). Most were based on 10 or less exposed cases, with the exception of a study from Canada (Demers et al., 1993) which reported an odds ratio of 1.2 (95% CI, 0.7–2.0) for welders and cutters based on 22 exposed cases. One of the five studies (Costantini et al., 2001) reported a statistically significant increased odds ratio for welders (OR, 3.3; 95% CI, 1.3–8.5) based on 7 exposed cases.

(d) Other haematopoietic cancers: Hodgkin lymphoma

The Working Group identified three case–control studies of Hodgkin lymphoma in adults that reported risk estimates for welding-related jobs (Persson et al., 1989; Persson et al., 1993; Costantini et al., 2001), all based on a small number of exposed cases. The oldest of these reported a statistically significant increased odds ratio (Persson et al., 1989). [The Working Group noted that information on the number of cases exposed was not available for this study but, given the size of the study and the wide confidence interval, it is expected to be small.]

2.5.4 Cancer of the urinary bladder

See Table 2.9 (web only; available at: http://publications.iarc.fr/569)

The Working Group identified 18 case–control studies on cancer of the urinary bladder (Howe et al., 1980; Silverman et al., 1983, 1989a, b, 1990; Schifflers et al., 1987; Claude et al., 1988; Risch et al., 1988; Burns & Swanson, 1991; Siemiatycki, 1991; Kunze et al., 1992; Zaridze et al., 1992; Cordier et al., 1993; Teschke et al., 1997; Colt et al., 2004; Gaertner et al., 2004; Samanic et al., 2008; Colt et al., 2011) and one pooled case–control study (Kogevinas et al., 2003) that reported on the association between cancer of the bladder and welding-related occupations or exposure to welding fumes. [The Working Group excluded two studies from Islamic Republic of Iran because the occupational group was too broad (Aminian et al., 2014; Ghadimi et al., 2015). To avoid duplicate inclusion, one study from Italy (Porru et al., 1996) was not included because it was included in the pooled analysis also listed in the table (Kogevinas et al., 2003).]

Most of the individual studies were conducted in Canada, Europe, or the USA and ranged in size from 74 to 2160 cases, most including incident cases of cancer of the bladder. Most presented risk estimates were adjusted for smoking. [The Working Group noted that the odds ratios presented in Silverman et al. (1983) were not adjusted for smoking, although the study authors reported that smoking adjustment did not change the results.] Most of the reported risk estimates for welding-related occupations from cancer of the bladder case–control studies were close to unity and did not reach statistical significance; the exception was the earliest study from Canada (Howe et al., 1980), which reported an odds ratio of 2.8 (95% CI, 1.1–8.8) based on 16 exposed cases. Several studies reported risk estimates close to unity based on a relatively large number of exposed cases (> 20) (e.g. Silverman et al., 1989b; Burns & Swanson, 1991; Cordier et al., 1993).

Three studies reported on the duration of employment as a welder. A large study from Canada reported an odds ratio of 0.93 (95% CI, 0.78–1.10) for a 10-year increment of duration of employment as a welder (Risch et al., 1988). A later study from Canada (Gaertner et al., 2004) reported an odds ratio of 1.66 (95% CI, 0.78–3.48) for the group with the longest duration of employment as a welder (> 15 years) compared with those never employed as a welder. A study from Spain (Samanic et al., 2008) reported an odds ratio of 1.32 (95% CI, 0.74–2.36) for the group with the longest duration of employment as a welder (≥ 10 years) compared with those never employed as a welder.

The largest cancer of the bladder case–control study reporting on employment as a welder, a pooled analysis of 11 cancer of the bladder case–control studies from six European countries (Kogevinas et al., 2003), reported a pooled odds ratio of 1.22 (95% CI, 0.91–1.63) after adjusting for age, smoking, and study centre, based on 88 exposed cases (men only). [The Working Group noted there was no overlap between this pooled study and the other studies listed in Table 2.9 (web only; available at: http://publications.iarc.fr/569). The Cordier et al. (1993) estimate for ever worked as a welder was included in the pooled estimate, but not the estimates for exposure to specific welding fumes reported on in the following paragraph and in the table.] Risk estimates by duration of employment as a welder were not reported.

Two studies used expert assessment, based on detailed work histories completed by the cases and the controls, to identify exposure to welding fumes generally and gas welding fumes versus arc welding fumes specifically. A study from Canada (Siemiatycki, 1991), using patients diagnosed with cancers other than bladder as controls, reported an odds ratio of 1.2 (95% CI, 0.9–1.5) for both arc welding fumes and gas welding fumes, based on 63 exposed cases. [The Working Group noted that the odds ratios were the same and based on the same numbers of exposed cases for both types of welding fume, suggesting that all cases were assessed by the experts as exposed to both gas welding and arc welding fumes.] Risk estimates did not increase when restricting the exposed group to those with "substantial" exposure. A study from France (Cordier et al., 1993) reported that exposure to any type of welding fumes was associated with an odds ratio of 1.40 (95% CI, 0.98–2.01) based on 86 exposed cases. An odds ratio of 1.61 (95% CI, 0.95–2.72) was reported for gas welding fumes and of 1.34 (95% CI, 0.79–2.27) for arc welding fumes, based on 40 and 37 exposed cases, respectively. [The Working Group noted that the numbers exposed to gas welding fumes and arc welding fumes would suggest that these groups were not fully, but largely, mutually exclusive.] Only 4 cases were exposed to SS welding fumes (OR, 1.10; 95% CI, 0.24–5.05). Risk estimates by level or duration of exposure to welding fumes were not reported.

(a) Subtypes of cancer of the bladder

With transitional cell carcinoma (TCC) being the dominant histological type of malignant tumours of the urinary bladder in industrialized countries (Fortuny et al., 1999), studies generally lacked statistical power to report on occupational risk factors for non-TCC of the bladder, including squamous cell carcinomas and adenocarcinomas. The above-mentioned pooled analysis of 11 case–control studies on cancer of the bladder from six European countries (Kogevinas et al., 2003) also reported on occupational risk factors for the 146 cases with non-TCC of the bladder (Fortuny et al., 1999), but an odds ratio specific to welding was not presented. The Working Group identified one study that reported a relative risk for welders, specifically for squamous cell carcinoma (RR, 5.9), based on 5 exposed cases; it was reported as being statistically significant, but the 95% confidence interval and *P* value were not provided (Kantor et al., 1988). Relative risks for all types of cancer of the bladder or adenocarcinoma of the bladder for welders were not significantly increased. [The Working Group noted that no further details were provided and that the study population overlaps that of Silverman et al. (1983); this study is therefore not included in the table.]

(b) Meta-analysis of cancer of the bladder

A meta-analysis of cohort and case–control studies that reported on the association between occupation and cancer of the bladder (all adjusted for smoking) was published in 2008 (Reulen et al., 2008), including 14 of the reports listed in Table 2.9 (web only; available at: http://publications.iarc.fr/569)

The meta-estimate for case–control studies was 1.04 (95% CI, 0.88–1.23). [The Working Group noted a major limitation in that the pooled analysis of 11 case–control studies on cancer of the bladder from six European countries (Kogevinas et al., 2003), which had already published by the time of the meta-analysis, was not included.]

2.5.5 *Cancers of the head, neck, and upper aerodigestive tract*

See Table 2.10 (web only; available at: http://publications.iarc.fr/569)

Studies on specific cancers of the head and neck are reviewed in the following. Two other studies reported results for all cancers of the head and neck combined. A case–control study which was part of the ICARE (Investigation of Occupational and Environmental Causes of Respiratory Cancers) study in France reported risk estimates for occupations and duration of occupation, adjusted for tobacco and alcohol consumption, separately for women (296 cases and 775 controls) (Carton et al., 2014) and men (1833 cases and 2747 controls) (Paget-Bailly et al., 2013). Odds ratios of 2.18 (95% CI, 0.33–14.4) and 21.7 (95% CI, 1.54–304) were reported for women who had ever worked as welders and flame-cutters (4 cases) and for women who had been employed for 10 years or more in this occupational group, respectively (*P* for trend, 0.05) (Carton et al., 2014). For men who had ever worked as welders and flame-cutters (109 cases) or who had been employed for 10 years or more in this occupational group, odds ratios of 1.9 (95% CI, 1.3–2.8) and 2.0 (95% CI, 1.0–3.9) were reported, respectively (*P* for trend, 0.01) (Paget-Bailly et al., 2013). Odds ratios for type of welding were also reported for men: 3.2 (95% CI, 1.6–6.3) for gas and electric welders (44 cases) and 1.9 (95% CI, 1.0–3.6) for electric arc welders (36 cases). Paget-Bailly et al. (2013) also reported odds ratios for specific head and neck cancer sites, particularly elevated for cancers of the hypopharynx (OR, 2.1; 95% CI, 1.2–3.6), oral cavity (see Section 2.5.5(c) below), and larynx (see Section 2.5.5(d) below).

(a) Cancer of the nasal cavity and sinuses

See Table 2.10 (web only; available at: http://publications.iarc.fr/569)

The Working Group identified four case–control studies that reported on welding or exposure to welding fumes (Hernberg et al., 1983; Luce et al., 1993; Teschke et al., 1997; d'Errico et al., 2009). These studies were all relatively small (48–207 cases), but a pooled analysis (Leclerc et al., 1997) included 930 cases. [The Working Group noted that the Luce et al. (1993) study population was included in this pooled analysis.]

Two of these four studies (Hernberg et al., 1983; Teschke et al., 1997) and the pooled analysis (Leclerc et al., 1997) reported odds ratios for welding-related occupations. A study from Denmark, Finland, and Sweden (Hernberg et al., 1983) reported an odds ratio of 2.8 (95% CI, 1.2–6.9) based on 17 exposed cases, noting that 13 were also exposed to chromium and/or nickel (as assessed by experts). A small study from Canada (Teschke et al., 1997) reported an odds ratio of 3.5 (95% CI, 0.2–53.7) based on 2 exposed cases. The pooled analysis (Leclerc et al., 1997) reported an odds ratio of 0.92 (95% CI, 0.38–2.22) based on 6 exposed cases.

Two studies assessed exposure to welding fumes through expert assessment. A study from France (Luce et al., 1993) reported odds ratios for exposure to welding fumes of 0.5 (95% CI, 0.2–1.4) for squamous cell carcinoma and 0.8 (95% CI, 0.4–1.6) for adenocarcinoma. A study from Italy (d'Errico et al., 2009) reported an odds ratio of 2.0 (95% CI, 1.00–3.82) for ever exposure to welding fumes based on 17 exposed cases, noting that additional adjustment for exposure to wood dust further strengthened the association (OR, 2.70; 95% CI, 1.31–5.45). Odds ratios by duration of exposure to welding fumes were also presented, with one of 2.40 (95% CI, 0.92–6.38) for 1–10 years of exposure to welding fumes and 3.0 (95% CI, 1.13–8.0) for more than 10 years. Odds ratios by level of welding fumes (low/high) were also reported, with 3.30 (95% CI, 1.47–7.26) and 1.60 (95% CI, 0.34–7.75) for low and high exposure levels, respectively. The odds ratio for exposure to welding fumes was reported as 4.30 (95% CI, 1.01–18.10) for squamous cell carcinoma and 1.30 (95% CI, 0.52–3.52) for adenocarcinoma (d'Errico et al., 2009).

[The Working Group noted that results stratified by the material being welded, which could evaluate the potential effect of exposure to chromium and nickel, were not presented in the identified studies. Results adjusted for wood dust suggest that wood dust is not a strong confounder in associations between welding and cancers of the nasal cavity and sinuses.]

(b) Cancer of the nasopharynx

One case–control study conducted in Hong Kong Special Administrative Region, China, on carcinomas of the nasopharynx was identified (Xie et al., 2017), reporting an odds ratio of 9.18 (95% CI, 1.05–80.35) for self-reported expose to welding fumes at any time in the job history, based on 7 exposed cases and 1 exposed control. [The Working Group noted that carcinomas of the nasopharynx differ from other cancers of the head and neck in terms of occurrence and identified risk factors. They are more common in certain geographical areas, including east Asia where this study is set, and found to be strongly linked to infection with the Epstein–Barr virus.]

(c) Cancer of the oral cavity and oropharynx

The Working Group identified five case–control studies on cancer of the oral cavity and/or oropharynx (Vaughan, 1989; Merletti et al., 1991; Huebner et al., 1992; Gustavsson et al., 1998; Paget-Bailly et al., 2013). With the exception of the study from France (Paget-Bailly et al., 2013), all reported odds ratios close to unity for welding-related occupations. Paget-Bailly et al. (2013) reported an odds ratio for cancer of the oral cavity of 1.9 (95% CI, 1.1–3.3) based on 21 cases that had ever worked as a welder or flame-cutter.

(d) Cancer of the larynx

The Working Group identified 10 case–control studies on cancer of the larynx that reported on welding or exposure to welding fumes (Olsen et al., 1984; Brown et al., 1988; Ahrens et al., 1991; Wortley et al., 1992; Goldberg et al., 1997; De Stefani et al., 1998; Gustavsson et al., 1998; Elci et al., 2001; Shangina et al., 2006; Paget-Bailly et al., 2013).

Seven of these studies reported on welding occupations (Brown et al., 1988; Ahrens et al., 1991; Wortley et al., 1992; Goldberg et al., 1997; De Stefani et al., 1998; Elci et al., 2001; Paget-Bailly et al., 2013). Four of the studies reported odds ratios at or below unity, while three reported an odds ratio above unity (Brown et al., 1988; Goldberg et al., 1997; Paget-Bailly et al., 2013); one of these (Paget-Bailly et al., 2013) [already discussed above (at the beginning of Section 2.5.5) in relation to all cancers of the head and neck combined] reported an odds ratio for cancer of the larynx of 2.4 (95% CI, 1.5–4.0) for men who had ever worked as a welder and flame-cutter (33 exposed cases). An additional international case–control study on cancer of the larynx (Boffetta et al., 2003) reported that an increased risk for welders was not observed, but an odds ratio was not reported (this study was therefore not included in the table). [The Working Group identified one study that reported results by duration of welding employment (Wortley et al., 1992), but the number of exposed cases was small and a trend was not observed.]

Three studies reported on the association between cancer of the larynx and exposure to welding fumes (Olsen et al., 1984; Gustavsson et al., 1998; Shangina et al., 2006). The earliest published study (Olsen et al., 1984), based in Denmark, reported an odds ratio for all cancers of the larynx combined of 1.3 (95% CI, 0.9–2.0) based on 42 cases that reported exposure to welding fumes. Results by type of cancer of the larynx were also presented, with an odds ratio of 1.1 (95% CI, 0.7–1.8) for glottic (23 exposed cases), 1.5 (95% CI, 0.8–2.9) for supraglottic (13 exposed cases), and 6.3 (95% CI, 1.8–21.6) for subglottic (5 exposed cases). A relatively large study from Sweden (Gustavsson et al., 1998) reported an odds ratio of 1.56 (95% CI, 0.92–2.53) for cancer of the larynx associated with ever exposure to welding fumes (based on 32 exposed cases), and a positive duration–response association was reported (*P* for trend, 0.04). A study from central and eastern Europe (Shangina et al., 2006), including 316 cases of cancer of the larynx and 34 cases of cancer of the hypopharynx, reported an odds ratio of 0.78 (95% CI, 0.54–1.14) for exposure to arc welding fumes (56 exposed cases) and 0.89 (95% CI, 0.58–1.37) for exposure to gas welding fumes (42 exposed cases).

(e) Cancer of the oesophagus

The Working Group identified four case–control studies on cancer of the oesophagus that reported on welding or exposure to welding fumes (Magnani et al., 1987; Siemiatycki, 1991; Gustavsson et al., 1998; Engel et al., 2002), all reporting odds ratios close to unity. Siemiatycki (1991) reported odds ratios for arc welding and gas welding separately, and for any as well as substantial exposure to welding fumes, but none were above unity.

2.5.6 Cancer of the brain

See Table 2.11 (web only; available at: http://publications.iarc.fr/569)

Six case–control studies investigating the risk of either malignant cancer of the brain or meningioma (a commonly diagnosed benign brain tumour) were identified by the Working Group.

Four studies were cancer of the brain case–control studies conducted in Canada, the UK, and the USA using either JEMs, job title, or exposure questionnaires, reporting on the association between malignant cancer of the brain and welding-related occupations or exposure to welding fumes (Magnani et al., 1987; Carozza et al., 2000; Pan et al., 2005; Ruder et al., 2012). Three of these studies reported odds ratios below or close to unity (Magnani et al., 1987; Carozza et al., 2000; Ruder et al., 2012), all based on a small number of exposed cases. The fourth, a large study of 1009 cases and 5039 matched controls (Pan et al., 2005), collected information on 18 employment-related chemical exposures including "welding", and reported an elevated odds ratio of 1.26 (95% CI, 0.98–1.45) based on 183 exposed cases. The same study found a 40% increase in risk of cancer of the brain in relation to duration of welding, with an odds ratio of 1.41 (95% CI, 0.98–1.84) in those exposed to welding fumes for 20 years or more (48 cases) compared with the reference group of non-exposed.

Two studies included exclusively meningiomas (Hu et al., 1999; Sadetzki et al., 2016). The first, a study from China using self-reported occupational exposures and hospital-recruited cases and controls (Hu et al., 1999), reported an odds ratio for exposure to welding rod fumes of 1.99 (95% CI, 0.40–9.89) for men based on 4 exposed cases and 3.05 (95% CI, 0.52–18.03) for women based on 5 exposed cases. The second, a large and recent international case–control study on meningioma (Sadetzki et al., 2016), reported that ever exposure to welding fumes, assessed using an updated version of FINJEM, was associated with risk of meningioma; an odds ratio of 1.19 (95% CI, 0.91–1.56) was reported, based on 94 exposed cases. Odds ratios were also reported separately for women (OR, 1.79; 95% CI, 0.78–4.10; 12 exposed cases) and men (OR, 1.15; 95% CI, 0.86–1.54; 82 exposed cases).

2.5.7 Parental exposure and cancer in offspring

See Table 2.12 (web only; available at: http://publications.iarc.fr/569)

Several case–control studies on childhood cancers have reported on the association between occupation of a parent (mostly father) as a welder and the risk of cancer in their offspring; no studies on childhood leukaemia were identified.

(a) All childhood cancers

One study conducted in Moscow reported on the association between the father's welding history before conception (Smulevich et al., 1999) and all childhood cancers combined. The number of fathers working as welders was significantly higher among cases than among controls, yielding an odds ratio of 1.8. [The Working Group noted that a breakdown of the specific childhood cancer sites was not provided, and no confidence interval was reported.]

(b) Childhood cancer of the central nervous system

A neuroblastoma case–control study evaluating parental occupation from age 18 onwards as a potential risk factor (Olshan et al., 1999) reported an odds ratio for father's occupation as a welder/cutter of 0.5 (95% CI, 0.1–1.6). A childhood central nervous system tumour case–control study focusing on paternal occupations with exposure to electric and magnetic fields (Wilkins & Wellage, 1996) reported an odds ratio for preconception paternal occupation as welder of 1.75 (95% CI, 0.23–13.21) based on 3 exposed case fathers and an odds ratio of paternal occupation as welder during pregnancy of 1.00 (95% CI, 0.09–11.03) based on 2 exposed case fathers. A broader definition of welding, also including those jobs with welding tasks (welding-related jobs), yielded an odds ratio for preconception paternal welding-related job of 3.83 (95% CI, 0.95–15.55) based on 6 exposed case fathers. [The Working Group noted that the higher odds ratio obtained when using a broader definition of welding-related jobs may suggest that exposures other than welding may have to be considered.] A large international case–control study on childhood brain tumours and parental occupations (Cordier et al., 2001) reported an odds ratio of 0.97 (95% CI, 0.50–1.70) for paternal occupation as a welder. [The Working Group noted that the number of exposed cases on which this odds ratio was based was not reported, but estimated that it was based on 19–20 exposed cases according to the reported percentage exposed controls.]

(c) Wilms' tumour

The Working Group identified four case–control studies on Wilms' tumour (a childhood neoplasm of the kidney) that evaluated the association with parental welding, three of which were too small to be able to report risk estimates (Kantor et al., 1979; Wilkins & Sinks, 1984; Bunin et al., 1989). The largest study (Olshan et al., 1990) included 200 cases and 233 controls. Among different exposure periods explored (i.e. preconception, pregnancy, and postnatal), 6 of the case fathers and 1 of the control fathers worked as a welder during pregnancy, yielding the highest odds ratio of 8.22 (95% CI, 0.95–71.27).

(d) Other childhood cancers

A case–control study on hepatoblastoma (Buckley et al., 1989) reported an odds ratio of 1.0 related to self-reported father's exposure to welding, based on 12 exposed case fathers. A case–control study of childhood sporadic bilateral retinoblastoma (Abdolahi et al., 2013) reported an odds ratio of 1.22 (95% CI, 0.68–2.19) associated with paternal ever exposure to welding fumes, as assessed by experts using the detailed job history, based on 29 exposed case fathers. The same study reported no risk in relation to intensity of exposure to welding fumes (comparing none to low with moderate and high levels), either during the 10 years before conception or during the year before conception only, and no trends in risk were observed. A recent data linkage study from Finland, Norway, and Sweden (Togawa et al., 2016) included 8112 cases of testicular germ cell tumour (age, 14–49 years) and 26 264 controls;

the occupation of participants' parents were obtained from the census, and exposure was assessed by applying a JEM. Paternal low exposure to welding fumes based on 953 exposed cases and 2904 exposed controls lead to an odds ratio of 1.09 (95% CI, 1.01–1.18), which decreased at high exposure levels to 0.97 (95% CI, 0.79–1.19), based on 124 exposed cases. The odds ratios for maternal exposure were 1.02 (95% CI, 0.65–1.59) and 1.23 (95% CI, 0.64–2.36) for exposure to low and high levels of welding fumes, respectively.

2.5.8 Cancer of the pancreas

See Table 2.13 (web only; available at: http://publications.iarc.fr/569)

A total of five case–control studies on cancer of the pancreas that reported on the association with welding or exposure to welding fumes were identified (Norell et al., 1986; Magnani et al., 1987; Siemiatycki, 1991; Ji et al., 1999; Luckett et al., 2012). [The Working Group did not include several other studies for evaluation (Ji et al., 1999; Alguacil et al., 2000; Luckett et al., 2012) as the occupational category was too broad.]

Three studies assessed exposure to welding fumes or "welding materials". A small case–control study from Sweden (Norell et al., 1986) reported an odds ratio of 2.0 (90% CI, 0.9–4.3) associated with exposure to "welding materials" based on 13 exposed cases. [The Working Group noted that the exact definition of "welding materials" was not reported.] A mortality study that used a JEM to assess exposure to welding fumes (Magnani et al., 1987) reported an odds ratio of 1 [the Working Group noted that the number of exposed cases was not reported]. A study using other cancer cases as controls (Siemiatycki, 1991), and expert assessment of exposure to arc welding fumes and gas welding fumes, reported odds ratios close to unity for any exposure to either type of fumes and substantial exposure to arc welding fumes; an odds ratio for substantial exposure to gas welding fumes of 1.4 (95% CI, 0.7–2.8) was reported, based on 6 exposed cases.

None of the studies reported relative risks by duration of exposure.

2.5.9 Other cancers

See Table 2.14 (web only; available at: http://publications.iarc.fr/569)

(a) Cancer of the stomach

The Working Group identified three case–control studies on cancer of the stomach that reported on associations with welding or exposure to welding fumes (Siemiatycki, 1991; Keller & Howe, 1993; Engel et al., 2002). Two studies from the USA reported risk estimates for welding occupation; one reported an odds ratio of 2.11 (95% CI, 1.09–4.09) for cancer of the stomach (Keller & Howe, 1993); and another reported an odds ratio of 2.0 (95% CI, 0.8–5.2) for adenocarcinoma of the gastric cardia and 0.8 (95% CI, 0.3–2.3) for adenocarcinoma of the gastric noncardia (Engel et al., 2002). A Canadian case–control study on cancer of the stomach that used expert assessment and cancer controls reported an odds ratio of 0.9 (95% CI, 0.6–1.3) for exposure to arc welding fumes and 0.9 (95% CI, 0.6–1.3) for exposure to gas welding fumes (Siemiatycki, 1991). [The Working Group noted that the estimates were likely to have been based on the same cases and controls, assessed as being exposed to both gas and arc welding fumes.]

(b) Cancer of the small bowel

The Working Group identified one case–control study on adenocarcinoma of the small bowel that included 79 cases from five countries (Kaerlev et al., 2000). An odds ratio of 2.6 (95% CI, 1.0–6.4; 6 exposed cases) was reported for welders and flame-cutters, with a positive duration–response relationship (*P* for trend, 0.01).

(c) Cancer of the colon and rectum

Three case–control studies on cancer of the colon were identified that examined the association with a welding-related occupation or exposure to welding fumes (Siemiatycki, 1991; Keller & Howe, 1993; Fang et al., 2011), reporting odds ratios ranging from 0.49 to 1.10, none reaching statistical significance. One of these studies also investigated the increased risk of cancer of the rectum in relation to exposure to welding fumes, reporting odds ratios close to unity (Siemiatycki, 1991).

(d) Cancer of the liver

One case–control study on cancer of the liver was identified that reported on the association between cancer of the liver and exposure to welding fumes, as assessed by expert (Kauppinen et al., 1992). Odds ratios adjusted for alcohol consumption of 1.38 (95% CI, 0.52–3.64), based on 6 exposed cases, and 13.40 (95% CI, 2.02–88.1) for exposure to high levels of welding fumes, based on 5 exposed cases, were reported.

(e) Cancer of the prostate

The Working Group identified four case–control studies on cancer of the prostate that reported on the association with welding or exposure to welding fumes. A Canadian study using expert assessment and cancer controls reported odds ratios of 1.7 (95% CI, 1.0–2.6) and 1.4 (95% CI, 0.9–2.1) for exposure to substantial levels of arc welding fumes and gas welding fumes, respectively (Siemiatycki, 1991). [The Working Group noted that the estimates are likely to have been based on largely the same cases and controls, assessed as being exposed to both gas and arc welding fumes.] A case–control study from the Netherlands (van der Gulden et al., 1995) reported an odds ratio of 1.51 (95% CI, 0.48–4.78; 4 cases) for longest-held occupation as welder and an odds ratio of 1.19 (95% CI, 0.73–1.95; 22 cases) for workers “frequently exposed to welding fumes”. A study from the US reported an odds ratio of 1.0 (95% CI, 0.61–1.64) for welders (Keller & Howe, 1993). A recent cancer of the prostate case–control study from Canada (Sauvé et al., 2016) reported an odds ratio of 0.97 (95% CI, 0.62–1.50; 50 cases) for ever having worked in welding and flame-cutting occupations. Odds ratios by duration of employment in the occupational group, and separately for arc welders and gas welders, were also presented, but did not reveal a positive duration–response association or differences in risk estimates between welding types.

(f) Cancer of the testis

The Working Group identified one case–control study on cancer of the testis that reported a risk estimate for a welding-related occupation (Walschaerts et al., 2007), with an odds ratio of 1.49 (95% CI, 0.53–4.15) after adjusting for risk factors, based on 20 exposed cases. [The Working Group identified an additional case–control study on testicular germ cell tumours, addressing parental occupation (Togawa et al., 2016); see also Section 2.5.7.]

(g) Melanoma of the skin

The Working Group identified two case–control studies on skin melanoma that reported on the association with exposure to welding fumes, both reporting odds ratios close to and below unity (Magnani et al., 1987; Siemiatycki, 1991).

2.6 Occupational studies of cancer mortality and incidence based on routinely collected data

See Table 2.15

Several studies conducted in Canada, New Zealand, the UK, and the USA evaluated the relationship between occupation and cancer using occupation reported on death certificates.

Table 2.15 Occupational studies on cancer mortality and incidence based on routinely collected data

Reference	Location	Exposure group	Cancer outcome and outcome measure	Risk estimate (95% CI)
Menck & Henderson (1976)	CA, USA	Welders	Lung; mortality and incidence: SMR	1.37 (1.01–1.81), 21 deaths, 27 cases
Decouflé et al. (1977)	NY, USA	Welders and flame cutters	Lung; incidence: RR (smoking adjusted)	0.67 (NR), 11 cases
Logan (1982)	UK	Welders	Lung; mortality: SMR	1951: 1.18 (NR) 1971: 1.51 (NR)
Gallagher & Threlfall (1983)	BC, Canada	Welders	Lung; mortality: PMR	1.45 (1.15–1.83), 74 deaths
Firth et al. (1993)	New Zealand	Welders	Lung; mortality: SMR	1.40 (1.20–1.61)
Coggon et al. (2009)	UK	Welders (men)	Mortality: PMR	
			Lung	1.11 (1.05–1.17), 1263 deaths
			Pleura	1.40 (1.04–1.86), 49 deaths
			Sinonasal	0.61 (0.13–1.78), 3 deaths
NIOSH (2015) National Occupational Mortality Surveillance (NOMS)	USA	Welders and cutters All races/sexes combined (1999, 2003–2004, 2007–2010)	Mortality: PMR	
			Lung	1.22 (1.21–1.30) 1975 deaths
			Oral cavity and pharynx	1.35 (1.11–1.63), 109 deaths
			Oesophagus	1.31 (1.13–1.52), 180 deaths
			Sinonasal	1.72 (0.79–3.27), 9 deaths
			Larynx	1.78 (1.38–2.25), 69 deaths
			Mesothelioma	2.88 (2.24–3.66), 68 deaths
			Liver and gall bladder	1.17 (1.03–1.33), 241 deaths
			Urinary bladder	1.25 (1.05–1.47), 141 deaths
			Kidney	0.99 (0.82–1.17), 130 deaths
			Prostate	1.79 (1.62–1.78), 395 deaths
			Brain	0.60 (0.48–0.75), 85 deaths
			Eye	–, < 5 deaths
			Chronic myeloid leukaemia	0.86 (0.39–1.63), 9 deaths
			Acute myeloid leukaemia	0.89 (0.69–1.12), 67 deaths
			Lymphatic leukaemia	1.02 (0.77–1.34), 53 deaths
			Multiple myeloma	0.77 (0.61–0.97), 76 deaths
			Non-Hodgkin lymphoma	0.82 ((0.70–0.96), 159 deaths
Dolin & Cook-Mozaffari (1992)	UK	Welders	Urinary bladder; mortality: SMR	0.74 (0.38–1.29)
Firth et al. (1993)	New Zealand	Welders	Stomach; mortality: SMR	1.45 (significant)

CI, confidence interval; PMR, proportional mortality ratio; RR, relative risk; SMR, standardized mortality ratio

Less frequently, cancer incidence data from various sources (e.g. not a newly assembled cohort) have also been used. Other countries have also conducted such studies on an ad hoc basis. Most studies were described by the Working Group in 1990 (IARC, 1990), but some have been updated or extended since then. [These studies are not described in detail (see Table 2.15 for a summary) due to several limitations, including: (1) lack of detailed exposure information or the use of occupation reported on death certificates; (2) limited information on potential confounders; (3) use of different data sources for observed (death certificates) and expected (census) deaths; and (4) chance findings due to multiple comparisons in evaluating the associations between many different occupations and causes of deaths in the USA (NIOSH, 2015) and the UK (Coggon et al., 2009).] These studies have been used repeatedly for occupational mortality surveillance purposes, and only the most recent update is reported.

Among all the studies that reported on cancer of the lung in welders, an excess of cancer of the lung was found in all but one study. The two studies that reported on cancer of the pleura and/or mesothelioma also found an excess among welders (Coggon et al., 2009; NIOSH, 2015). Excesses of several other types of cancer were also reported, including cancers of the stomach (Firth et al., 1993), oral cavity and pharynx, oesophagus, larynx, liver and gall bladder, and urinary bladder (NIOSH, 2015). In contrast, no excess risk of cancer of the urinary bladder was found in a study in the UK (Dolin & Cook-Mozaffari, 1992). No clear excess of mortality from cancer of the nasal cavity and sinuses was apparent (Coggon et al., 2009; NIOSH, 2015), and no excesses of deaths from cancer of the kidney, cancer of the brain, leukaemia, multiple myeloma, or NHL were found in the only study that reported on these cancer sites (NIOSH, 2015).

References

Abdolahi A, van Wijngaarden E, McClean MD, Herrick RF, Allen JG, Ganguly A, et al. (2013). A case-control study of paternal occupational exposures and the risk of childhood sporadic bilateral retinoblastoma. *Occup Environ Med*, 70(6):372–9. doi:10.1136/oemed-2012-101062 PMID:23503471

Adegoke OJ, Blair A, Shu XO, Sanderson M, Jin F, Dosemeci M, et al. (2003). Occupational history and exposure and the risk of adult leukemia in Shanghai. *Ann Epidemiol*, 13(7):485–94. doi:10.1016/S1047-2797(03)00037-1 PMID:12932623

Ahrens W, Jöckel KH, Patzak W, Elsner G (1991). Alcohol, smoking, and occupational factors in cancer of the larynx: a case-control study. *Am J Ind Med*, 20(4):477–93. doi:10.1002/ajim.4700200404 PMID:1785612

Ajani UA, Seddon JM, Hsieh CC, Egan KM, Albert DM, Gragoudas ES (1992). Occupation and risk of uveal melanoma. An exploratory study. *Cancer*, 70(12):2891–900. doi:10.1002/1097-0142(19921215)70:12<2891::AID-CNCR2820701228>3.0.CO;2-1 PMID:1451071

Alguacil J, Pollán M, Gustavsson P (2003). Occupations with increased risk of pancreatic cancer in the Swedish population. *Occup Environ Med*, 60(8):570–6. doi:10.1136/oem.60.8.570 PMID:12883017

Alguacil J, Porta M, Benavides FG, Malats N, Kogevinas M, Fernández E, et al.; PANKRAS II Study Group (2000). Occupation and pancreatic cancer in Spain: a case-control study based on job titles. *Int J Epidemiol*, 29(6):1004–13. doi:10.1093/ije/29.6.1004 PMID:11101541

Aminian O, Saburi A, Mohseni H, Akbari H, Chavoshi F, Akbari H (2014). Occupational risk of bladder cancer among Iranian male workers. *Urol Ann*, 6(2):135–8. doi:10.4103/0974-7796.130643 PMID:24833825

Austin H, Delzell E, Lally C, Rotimi C, Oestenstad K (1997). A case-control study of lung cancer at a foundry and two engine plants. *Am J Ind Med*, 31(4):414–21. doi:10.1002/(SICI)1097-0274(199704)31:4<414::AID-AJIM6>3.0.CO;2-V PMID:9093655

AWS (1997). Standard welding terms and definitions. ANSI/AWS A3.0–94. Miami (FL), USA: American Welding Society.

Band PR, Le ND, Fang R, Gallagher R (2004). Identification of occupational cancer risks in British Columbia: a population-based case-control study of 769 cases of non-Hodgkin's lymphoma analyzed by histopathology subtypes. *J Occup Environ Med*, 46(5):479–89. doi:10.1097/01.jom.0000126028.99599.36 PMID:15167397

Baris D, Silverman DT, Brown LM, Swanson GM, Hayes RB, Schwartz AG, et al. (2004). Occupation, pesticide exposure and risk of multiple myeloma. *Scand J Work Environ Health*, 30(3):215–22. doi:10.5271/sjweh.782 PMID:15250650

Beaumont JJ, Weiss NS (1980). Mortality of welders, shipfitters, and other metal trades workers in boilermakers Local No. 104, AFL-CIO. *Am J Epidemiol*, 112(6):775–86. PMID:7457470

Beaumont JJ, Weiss NS (1981). Lung cancer among welders. *J Occup Med*, 23:839–44.

Becker N (1999). Cancer mortality among arc welders exposed to fumes containing chromium and nickel. Results of a third follow-up: 1989-1995. *J Occup Environ Med*, 41(4):294–303. doi:10.1097/00043764-199904000-00012 PMID:10224596

Becker N, Chang-Claude J, Frentzel-Beyme R (1991). Risk of cancer for arc welders in the Federal Republic of Germany: results of a second follow up (1983-8). *Br J Ind Med*, 48(10):675–83. PMID:1931726

Becker N, Claude J, Frentzel-Beyme R (1985). Cancer risk of arc welders exposed to fumes containing chromium and nickel. *Scand J Work Environ Health*, 11(2):75–82. doi:10.5271/sjweh.2242 PMID:4001902

Benhamou S, Benhamou E, Flamant R (1988). Occupational risk factors of lung cancer in a French case-control study. *Br J Ind Med*, 45(4):231–3. PMID:3377999

Bethwaite P, Cook A, Kennedy J, Pearce N (2001). Acute leukemia in electrical workers: a New Zealand case-control study. *Cancer Causes Control*, 12(8):683–9. doi:10.1023/A:1011297803849 PMID:11562108

Blot WJ, Harrington JM, Toledo A, Hoover R, Heath CW Jr, Fraumeni JF Jr (1978). Lung cancer after employment in shipyards during World War II. *N Engl J Med*, 299(12):620–4. doi:10.1056/NEJM197809212991202 PMID:683235

Blot WJ, Morris LE, Stroube R, Tagnon I, Fraumeni JF Jr (1980). Lung and laryngeal cancers in relation to shipyard employment in coastal Virginia. *J Natl Cancer Inst*, 65(3):571–5. PMID:6931936

Boffetta P, Richiardi L, Berrino F, Estève J, Pisani P, Crosignani P, et al. (2003). Occupation and larynx and hypopharynx cancer: an international case-control study in France, Italy, Spain, and Switzerland. *Cancer Causes Control*, 14(3):203–12. doi:10.1023/A:1023699717598 PMID:12814199

Bonde JP, Olsen JH, Hansen KS (1992). Adverse pregnancy outcome and childhood malignancy with reference to paternal welding exposure. *Scand J Work Environ Health*, 18(3):169–77. doi:10.5271/sjweh.1591 PMID:1615291

Brenner DR, Hung RJ, Tsao MS, Shepherd FA, Johnston MR, Narod S, et al. (2010). Lung cancer risk in never-smokers: a population-based case-control study of epidemiologic risk factors. *BMC Cancer*, 10(1):285 doi:10.1186/1471-2407-10-285 PMID:20546590

Breslow L, Hoaglin L, Rasmussen G, Abrams HK (1954). Occupations and cigarette smoking as factors in lung cancer. *Am J Public Health Nations Health*, 44(2):171–81. doi:10.2105/AJPH.44.2.171 PMID:13114492

Brown LM, Mason TJ, Pickle LW, Stewart PA, Buffler PA, Burau K, et al. (1988). Occupational risk factors for laryngeal cancer on the Texas Gulf Coast. *Cancer Res*, 48(7):1960–4. PMID:3349470

Brüning T, Pesch B, Wiesenhütter B, Rabstein S, Lammert M, Baumüller A, et al. (2003). Renal cell cancer risk and occupational exposure to trichloroethylene: results of a consecutive case-control study in Arnsberg, Germany. *Am J Ind Med*, 43(3):274–85. doi:10.1002/ajim.10185 PMID:12594774

Buckley JD, Sather H, Ruccione K, Rogers PC, Haas JE, Henderson BE, et al. (1989). A case-control study of risk factors for hepatoblastoma. A report from the Childrens Cancer Study Group. *Cancer*, 64(5):1169–76. doi:10.1002/1097-0142(19890901)64:5<1169::AID-CNCR2820640534>3.0.CO;2-I PMID:2547509

Buiatti E, Kriebel D, Geddes M, Santucci M, Pucci N (1985). A case control study of lung cancer in Florence, Italy. I. Occupational risk factors. *J Epidemiol Community Health*, 39(3):244–50. doi:10.1136/jech.39.3.244 PMID:4045367

Bunin GR, Nass CC, Kramer S, Meadows AT (1989). Parental occupation and Wilms' tumor: results of a case-control study. *Cancer Res*, 49(3):725–9. PMID:2535965

Burns PB, Swanson GM (1991). Risk of urinary bladder cancer among blacks and whites: the role of cigarette use and occupation. *Cancer Causes Control*, 2(6):371–9. doi:10.1007/BF00054297 PMID:1764561

Calvert GM, Luckhaupt S, Lee SJ, Cress R, Schumacher P, Shen R, et al. (2012). Lung cancer risk among construction workers in California, 1988-2007. *Am J Ind Med*, 55(5):412–22. doi:10.1002/ajim.22010 PMID:22237930

Carozza SE, Wrensch M, Miike R, Newman B, Olshan AF, Savitz DA, et al. (2000). Occupation and adult gliomas. *Am J Epidemiol*, 152(9):838–46. doi:10.1093/aje/152.9.838 PMID:11085395

Carton M, Guida F, Paget-Bailly S, Cyr D, Radoi L, Sanchez M, et al. (2014). Occupation and head and neck cancer in women-Results of the ICARE study. *Am J Ind Med*, 57(12):1386–97. doi:10.1002/ajim.22394 PMID:25351857

Claude JC, Frentzel-Beyme RR, Kunze E (1988). Occupation and risk of cancer of the lower urinary tract among men. A case-control study. *Int J Cancer*, 41(3):371–9. doi:10.1002/ijc.2910410309 PMID:3346100

Coggon D, Harris EC, Brown T, Rice S, Palmer KT (2009). Occupational mortality in England and Wales, 1991–2000. Newport, UK: Office for National Statistics, Health and Safety Executive. Available from: https://www.ons.gov.uk.

Colt JS, Baris D, Stewart P, Schned AR, Heaney JA, Mott LA, et al. (2004). Occupation and bladder cancer risk in a population-based case-control study in New Hampshire. *Cancer Causes Control*, 15(8):759–69. doi:10.1023/B:CACO.0000043426.28741.a2 PMID:15456989

Colt JS, Karagas MR, Schwenn M, Baris D, Johnson A, Stewart P, et al. (2011). Occupation and bladder cancer in a population-based case-control study in Northern New England. *Occup Environ Med*, 68(4):239–49. doi:10.1136/oem.2009.052571 PMID:20864470

Corbin M, McLean D, Mannetje A, Dryson E, Walls C, McKenzie F, et al. (2011). Lung cancer and occupation: A New Zealand cancer registry-based case-control study. *Am J Ind Med*, 54(2):89–101. doi:10.1002/ajim.20906 PMID:20957667

Cordier S, Clavel J, Limasset JC, Boccon-Gibod L, Le Moual N, Mandereau L, et al. (1993). Occupational risks of bladder cancer in France: a multicentre case-control study. *Int J Epidemiol*, 22(3):403–11. doi:10.1093/ije/22.3.403 PMID:8359955

Cordier S, Mandereau L, Preston-Martin S, Little J, Lubin F, Mueller B, et al. (2001). Parental occupations and childhood brain tumors: results of an international case-control study. *Cancer Causes Control*, 12(9):865–74. doi:10.1023/A:1012277703631 PMID:11714115

Costantini AS, Miligi L, Kriebel D, Ramazzotti V, Rodella S, Scarpi E, et al. (2001). A multicenter case-control study in Italy on hematolymphopoietic neoplasms and occupation. *Epidemiology*, 12(1):78–87. doi:10.1097/00001648-200101000-00014 PMID:11138825

Costantini AS, Miligi L, Vineis P; WILL (Working Group on Hematolymphopoietic Malignancies in Italy) (1998). [An Italian multicenter case-control study on malignant neoplasms of the hematolymphopoietic system. Hypothesis and preliminary results on work-related risks] *Med Lav*, 89(2):164–76. PMID:9673106

d'Errico A, Pasian S, Baratti A, Zanelli R, Alfonzo S, Gilardi L, et al. (2009). A case-control study on occupational risk factors for sino-nasal cancer. *Occup Environ Med*, 66(7):448–55. doi:10.1136/oem.2008.041277 PMID:19153109

Danielsen TE, Langård S, Andersen A (1998). Incidence of lung cancer among shipyard welders investigated for siderosis. *Int J Occup Environ Health*, 4(2):85–8. doi:10.1179/oeh.1998.4.2.85 PMID:10026469

Danielsen TE, Langård S, Andersen A (1996). Incidence of cancer among Norwegian boiler welders. *Occup Environ Med*, 53(4):231–4. doi:10.1136/oem.53.4.231 PMID:8664959

Danielsen TE, Langård S, Andersen A (2000). Incidence of cancer among welders and other shipyard workers with information on previous work history. *J Occup Environ Med*, 42(1):101–9. doi:10.1097/00043764-200001000-00023 PMID:10652696

Danielsen TE, Langård S, Andersen A, Knudsen O (1993). Incidence of cancer among welders of mild steel and other shipyard workers. *Br J Ind Med*, 50(12):1097–103. PMID:8280640

de Silva SR, Bundy ED, Smith PD, Gaydos JC (1999). A geographical information system technique for record-matching in a study of cancer deaths in welders. *J Occup Environ Med*, 41(6):464–8. doi:10.1097/00043764-199906000-00012 PMID:10390697

De Stefani E, Boffetta P, Oreggia F, Ronco A, Kogevinas M, Mendilaharsu M (1998). Occupation and the risk of laryngeal cancer in Uruguay. *Am J Ind Med*, 33(6):537–42. doi:10.1002/(SICI)1097-0274(199806)33:6<537::AID-AJIM3>3.0.CO;2-N PMID:9582944

Decouflé P, Stanislawczyk K, Houten L, Bross J, Viadana E (1977). Retrospective survey of cancer in relation to occupation. DHEW (NIOSH) Publication No. 77–178. Cincinnati (OH), USA: National Institute for Occupational Safety and Health.

Demers PA, Vaughan TL, Koepsell TD, Lyon JL, Swanson GM, Greenberg RS, et al. (1993). A case-control study of multiple myeloma and occupation. *Am J Ind Med*, 23(4):629–39. doi:10.1002/ajim.4700230410 PMID:8338527

Dolin PJ, Cook-Mozaffari P (1992). Occupation and bladder cancer: a death-certificate study. *Br J Cancer*, 66(3):568–78. doi:10.1038/bjc.1992.316 PMID:1520596

Droste JH, Weyler JJ, Van Meerbeeck JP, Vermeire PA, van Sprundel MP (1999). Occupational risk factors of lung cancer: a hospital based case-control study. *Occup Environ Med*, 56(5):322–7. doi:10.1136/oem.56.5.322 PMID:10472306

Dryver E, Brandt L, Kauppinen T, Olsson H (2004). Occupational exposures and non-Hodgkin's lymphoma in Southern Sweden. *Int J Occup Environ Health*, 10(1):13–21. doi:10.1179/oeh.2004.10.1.13 PMID:15070021

Dunn JE Jr, Linden G, Breslow L (1960). Lung cancer mortality experience of men in certain occupations in California. *Am J Public Health Nations Health*, 50(10):1475–87. doi:10.2105/AJPH.50.10.1475 PMID:13725049

Dunn JE Jr, Weir JM (1968). A prospective study of mortality of several occupational groups. Special emphasis on lung cancer. *Arch Environ Health*, 17(1):71–6. doi:10.1080/00039896.1968.10665192 PMID:5671094

Elci OC, Dosemeci M, Blair A (2001). Occupation and the risk of laryngeal cancer in Turkey. *Scand J Work Environ Health*, 27(4):233–9. doi:10.5271/sjweh.610 PMID:11560337

Engel LS, Vaughan TL, Gammon MD, Chow WH, Risch HA, Dubrow R, et al. (2002). Occupation and risk of esophageal and gastric cardia adenocarcinoma. *Am J Ind Med*, 42(1):11–22. doi:10.1002/ajim.10077 PMID:12111686

Englund A, Ekman G, Zabrielski L (1982). Occupational categories among brain tumor cases recorded in the cancer registry in Sweden. *Ann N Y Acad Sci*, 381(1):188–96. doi:10.1111/j.1749-6632.1982.tb50384.x PMID:6953789

Eriksson M, Karlsson M (1992). Occupational and other environmental factors and multiple myeloma: a population based case-control study. *Br J Ind Med*, 49(2):95–103. PMID:1536825

Fabbro-Peray P, Daures JP, Rossi JF (2001). Environmental risk factors for non-Hodgkin's lymphoma: a population-based case-control study in Languedoc-Roussillon, France. *Cancer Causes Control*, 12(3):201–12. doi:10.1023/A:1011274922701 PMID:11405325

Fang R, Le N, Band P (2011). Identification of occupational cancer risks in British Columbia, Canada: a population-based case-control study of 1,155 cases of colon cancer. *Int J Environ Res Public Health*, 8(10):3821–43. doi:10.3390/ijerph8103821 PMID:22073015

Figgs LW, Dosemeci M, Blair A (1995). United States non-Hodgkin's lymphoma surveillance by occupation 1984-1989: a twenty-four state death certificate study. *Am J Ind Med*, 27(6):817–35. doi:10.1002/ajim.4700270606 PMID:7645576

Firth HM, Herbison GP, Cooke KR, Fraser J (1993). Male cancer mortality by occupation: 1973-86. *N Z Med J*, 106(961):328–30. PMID:8341471

Fletcher AC, Ades A (1984). Lung cancer mortality in a cohort of English foundry workers. *Scand J Work Environ Health*, 10(1):7–16. doi:10.5271/sjweh.2361 PMID:6740279

Fortuny J, Kogevinas M, Chang-Claude J, González CA, Hours M, Jöckel KH, et al. (1999). Tobacco, occupation and non-transitional-cell carcinoma of the bladder: an international case-control study. *Int J Cancer*, 80(1):44–6. doi:10.1002/(SICI)1097-0215(19990105)80:1<44::AID-IJC9>3.0.CO;2-8 PMID:9935228

Gaertner RR, Trpeski L, Johnson KC; Canadian Cancer Registries Epidemiology Research Group (2004). A case-control study of occupational risk factors for bladder cancer in Canada. *Cancer Causes Control*, 15(10):1007–19. doi:10.1007/s10552-004-1448-7 PMID:15801485

Gallagher RP, Threlfall WJ (1983). Cancer mortality in metal workers. *Can Med Assoc J*, 129(11):1191–4. PMID:6640455

Gérin M, Fletcher AC, Gray C, Winkelmann R, Boffetta P, Simonato L (1993). Development and use of a welding process exposure matrix in a historical prospective study of lung cancer risk in European welders. *Int J Epidemiol*, 22:Suppl 2: S22–8. doi:10.1093/ije/22.Supplement_2.S22 PMID:8132388

Gerin M, Siemiatycki J, Richardson L, Pellerin J, Lakhani R, Dewar R (1984). Nickel and cancer associations from a multicancer occupation exposure case-referent study: preliminary findings. In: Sunderman FW, editor. Nickel in the human environment. Lyon, France: International Agency for Research on Cancer. IARC Scientific Publication No. 53, pp. 105–115.

Ghadimi T, Gheitasi B, Nili S, Karimi M, Ghaderi E (2015). Occupation, smoking, opium, and bladder cancer: A case-control study. *South Asian J Cancer*, 4(3):111–4. doi:10.4103/2278-330X.173174 PMID:26942139

Goldberg P, Leclerc A, Luce D, Morcet JF, Brugère J (1997). Laryngeal and hypopharyngeal cancer and occupation: results of a case control-study. *Occup Environ Med*, 54(7):477–82. doi:10.1136/oem.54.7.477 PMID:9282123

Guénel P, Laforest L, Cyr D, Févotte J, Sabroe S, Dufour C, et al. (2001). Occupational risk factors, ultraviolet radiation, and ocular melanoma: a case-control study in France. *Cancer Causes Control*, 12(5):451–9. doi:10.1023/A:1011271420974 PMID:11545460

Guida F, Papadopoulos A, Menvielle G, Matrat M, Févotte J, Cénée S, et al. (2011). Risk of lung cancer and occupational history: results of a French population-based case-control study, the ICARE study. *J Occup Environ Med*, 53(9):1068–77. doi:10.1097/JOM.0b013e318229ab2e PMID:21866050

Gustavsson P, Jakobsson R, Johansson H, Lewin F, Norell S, Rutkvist LE (1998). Occupational exposures and squamous cell carcinoma of the oral cavity, pharynx, larynx, and oesophagus: a case-control study in Sweden. *Occup Environ Med*, 55(6):393–400. doi:10.1136/oem.55.6.393 PMID:9764099

Gustavsson P, Jakobsson R, Nyberg F, Pershagen G, Järup L, Schéele P (2000). Occupational exposure and lung cancer risk: a population-based case-referent study in Sweden. *Am J Epidemiol*, 152(1):32–40. doi:10.1093/aje/152.1.32 PMID:10901327

Håkansson N, Floderus B, Gustavsson P, Johansen C, Olsen JH (2002). Cancer incidence and magnetic field exposure in industries using resistance welding in Sweden. *Occup Environ Med*, 59(7):481–6. doi:10.1136/oem.59.7.481 PMID:12107298

Håkansson N, Stenlund C, Gustavsson P, Johansen C, Floderus B (2005). Arc and resistance welding and tumours of the endocrine glands: a Swedish case-control study with focus on extremely low frequency magnetic fields. *Occup Environ Med*, 62(5):304–8. doi:10.1136/oem.2004.015479 PMID:15837851

Haldorsen T, Andersen A, Boffetta P (2004). Smoking-adjusted incidence of lung cancer by occupation among Norwegian men. *Cancer Causes Control*, 15(2):139–47. doi:10.1023/B:CACO.0000019485.74818.d6 PMID:15017126

Hansen EB (1982). A survey on welding and cutting in stainless steel in the Danish Industry. Copenhagen, Denmark: Copenhagen Svejsecentralen [Danish].

Hansen KS, Lauritsen JM, Skytthe A (1996). Cancer incidence among mild steel and stainless steel welders and other metal workers. *Am J Ind Med*, 30(4):373–82.

doi:10.1002/(SICI)1097-0274(199610)30:4<373::AID-AJIM1>3.0.CO;2-X PMID:8892541

Heineman EF, Olsen JH, Pottern LM, Gomez M, Raffn E, Blair A (1992). Occupational risk factors for multiple myeloma among Danish men. *Cancer Causes Control*, 3(6):555–68. doi:10.1007/BF00052753 PMID:1420859

Hernberg S, Westerholm P, Schultz-Larsen K, Degerth R, Kuosma E, Englund A, et al. (1983). Nasal and sinonasal cancer. Connection with occupational exposures in Denmark, Finland and Sweden. *Scand J Work Environ Health*, 9(4):315–26. doi:10.5271/sjweh.2405 PMID:6635610

Holly EA, Aston DA, Ahn DK, Smith AH (1996). Intraocular melanoma linked to occupations and chemical exposures. *Epidemiology*, 7(1):55–61. doi:10.1097/00001648-199601000-00010 PMID:8664402

Howe GR, Burch JD, Miller AB, Cook GM, Esteve J, Morrison B, et al. (1980). Tobacco use, occupation, coffee, various nutrients, and bladder cancer. *J Natl Cancer Inst*, 64(4):701–13. PMID:6928984

Howe GR, Fraser D, Lindsay J, Presnal B, Yu SZ (1983). Cancer mortality (1965-77) in relation to diesel fume and coal exposure in a cohort of retired railway workers. *J Natl Cancer Inst*, 70(6):1015–9. PMID:6574269

Hu J, Little J, Xu T, Zhao X, Guo L, Jia X, et al. (1999). Risk factors for meningioma in adults: a case-control study in northeast China. *Int J Cancer*, 83(3):299–304. doi:10.1002/(SICI)1097-0215(19991029)83:3<299::AID-IJC2>3.0.CO;2-Z PMID:10495419

Huebner WW, Schoenberg JB, Kelsey JL, Wilcox HB, McLaughlin JK, Greenberg RS, et al. (1992). Oral and pharyngeal cancer and occupation: a case-control study. *Epidemiology*, 3(4):300–9. doi:10.1097/00001648-199207000-00005 PMID:1637894

Hull CJ, Doyle E, Peters JM, Garabrant DH, Bernstein L, Preston-Martin S (1989). Case-control study of lung cancer in Los Angeles county welders. *Am J Ind Med*, 16(1):103–12. doi:10.1002/ajim.4700160111 PMID:2750746

IARC (1990). Chromium, nickel and welding. *IARC Monogr Eval Carcinog Risks Hum*, 49:1–648. Available from: http://publications.iarc.fr/67 PMID:2232124

IARC (2012a). Arsenic, metals, fibres, and dusts. *IARC Monogr Eval Carcinog Risks Hum*, 100(Pt C):11–465. Available from: http://publications.iarc.fr/120 PMID:23189751

IARC (2012b). Radiation. *IARC Monogr Eval Carcinog Risks Hum*, 100(Pt D):7–303. Available from http://publications.iarc.fr/121 PMID:23189752

Ji BT, Silverman DT, Dosemeci M, Dai Q, Gao YT, Blair A (1999). Occupation and pancreatic cancer risk in Shanghai, China. *Am J Ind Med*, 35(1):76–81. doi:10.1002/(SICI)1097-0274(199901)35:1<76::AID-AJIM10>3.0.CO;2-6 PMID:9884748

Jöckel K-H, Ahrens W, Bolm-Audorff U (1994). Lung cancer risk and welding–preliminary results from an ongoing case-control study. *Am J Ind Med*, 25(6):805–12. doi:10.1002/ajim.4700250605 PMID:8067358

Jöckel KH, Ahrens W, Pohlabeln H, Bolm-Audorff U, Müller KM (1998). Lung cancer risk and welding: results from a case-control study in Germany. *Am J Ind Med*, 33(4):313–20. doi:10.1002/(SICI)1097-0274(199804)33:4<313::AID-AJIM1>3.0.CO;2-V PMID:9513638

Kaerlev L, Teglbjaerg PS, Sabroe S, Kolstad HA, Ahrens W, Eriksson M, et al. (2000). Occupation and small bowel adenocarcinoma: a European case-control study. *Occup Environ Med*, 57(11):760–6. doi:10.1136/oem.57.11.760 PMID:11024200

Kantor AF, Curnen MG, Meigs JW, Flannery JT (1979). Occupations of fathers of patients with Wilms's tumour. *J Epidemiol Community Health*, 33(4):253–6. doi:10.1136/jech.33.4.253 PMID:231629

Kantor AF, Hartge P, Hoover RN, Fraumeni JF Jr (1988). Epidemiological characteristics of squamous cell carcinoma and adenocarcinoma of the bladder. *Cancer Res*, 48(13):3853–5. PMID:3378221

Karunanayake CP, McDuffie HH, Dosman JA, Spinelli JJ, Pahwa P (2008). Occupational exposures and non-Hodgkin's lymphoma: Canadian case-control study. *Environ Health*, 7(1):44 doi:10.1186/1476-069X-7-44 PMID:18687133

Kauppinen T, Riala R, Seitsamo J, Hernberg S (1992). Primary liver cancer and occupational exposure. *Scand J Work Environ Health*, 18(1):18–25. doi:10.5271/sjweh.1616 PMID:1313183

Keller JE, Howe HL (1993). Cancer in Illinois construction workers: a study. *Am J Ind Med*, 24(2):223–30. doi:10.1002/ajim.4700240208 PMID:8213848

Kendzia B, Behrens T, Jöckel KH, Siemiatycki J, Kromhout H, Vermeulen R, et al. (2013). Welding and lung cancer in a pooled analysis of case-control studies. *Am J Epidemiol*, 178(10):1513–25. doi:10.1093/aje/kwt201 PMID:24052544

Kjuus H, Skjaerven R, Langård S, Lien JT, Aamodt T (1986). A case-referent study of lung cancer, occupational exposures and smoking. I. Comparison of title-based and exposure-based occupational information. *Scand J Work Environ Health*, 12(3):193–202. doi:10.5271/sjweh.2158 PMID:3749833

Kogevinas M, 't Mannetje A, Cordier S, Ranft U, González CA, Vineis P, et al. (2003). Occupation and bladder cancer among men in Western Europe. *Cancer Causes Control*, 14(10):907–14. doi:10.1023/B:CACO.0000007962.19066.9c PMID:14750529

Kromhout H, Heederik D, Dalderup LM, Kromhout D (1992). Performance of two general job-exposure matrices in a study of lung cancer morbidity in the Zutphen cohort. *Am J Epidemiol*, 136(6):698–711. doi:10.1093/oxfordjournals.aje.a116549 PMID:1442736

Krstev S, Stewart P, Rusiecki J, Blair A (2007). Mortality among shipyard Coast Guard workers: a retrospective cohort study. *Occup Environ Med*, 64(10):651–8. doi:10.1136/oem.2006.029652 PMID:17881470

Kubale TL, Daniels RD, Yiin JH, Couch J, Schubauer-Berigan MK, Kinnes GM, et al. (2005). A nested case-control study of leukemia mortality and ionizing radiation at the Portsmouth Naval Shipyard. *Radiat Res*, 164(6):810–9. doi:10.1667/RR3473.1 PMID:16296888

Kunze E, Chang-Claude J, Frentzel-Beyme R (1992). Life style and occupational risk factors for bladder cancer in Germany. A case-control study. *Cancer*, 69(7):1776–90. doi:10.1002/1097-0142(19920401)69:7<1776::AID-CNCR2820690721>3.0.CO;2-P PMID:1551063

Lauritsen JM, Hansen KS (1996). Lung cancer mortality in stainless steel and mild steel welders: a nested case-referent study. *Am J Ind Med*, 30(4):383–91. doi:10.1002/(SICI)1097-0274(199610)30:4<383::AID-AJIM2>3.0.CO;2-X PMID:8892542

Leclerc A, Luce D, Demers PA, Boffetta P, Kogevinas M, Belli S, et al. (1997). Sinonasal cancer and occupation. Results from the reanalysis of twelve case-control studies. *Am J Ind Med*, 31(2):153–65. doi:10.1002/(SICI)1097-0274(199702)31:2<153::AID-AJIM4>3.0.CO;2-0 PMID:9028431

Lerchen ML, Wiggins CL, Samet JM (1987). Lung cancer and occupation in New Mexico. *J Natl Cancer Inst*, 79(4):639–45. PMID:3477658

Logan WPD (1982). Cancer mortality by occupation and social class 1851–1971. Lyon: International Agency for Research on Cancer. IARC Scientific Publication No. 36.

Luce D, Gérin M, Leclerc A, Morcet JF, Brugère J, Goldberg M (1993). Sinonasal cancer and occupational exposure to formaldehyde and other substances. *Int J Cancer*, 53(2):224–31. doi:10.1002/ijc.2910530209 PMID:8425759

Luckett BG, Su LJ, Rood JC, Fontham ET (2012). Cadmium exposure and pancreatic cancer in south Louisiana. *J Environ Public Health*, 2012:180186 doi:10.1155/2012/180186 PMID:23319964

Luckhaupt SE, Deapen D, Cress R, Schumacher P, Shen R, Calvert GM (2012). Leukemia among male construction workers in California, 1988-2007. *Leuk Lymphoma*, 53(11):2228–36. doi:10.3109/10428194.2012.690873 PMID:22563817

Luqman M, Javed MM, Daud S, Raheem N, Ahmad J, Khan AU (2014). Risk factors for lung cancer in the Pakistani population. *Asian Pac J Cancer Prev*, 15(7):3035–9. doi:10.7314/APJCP.2014.15.7.3035 PMID:24815443

Lutz JM, Cree I, Sabroe S, Kvist TK, Clausen LB, Afonso N, et al. (2005). Occupational risks for uveal melanoma results from a case-control study in nine European countries. *Cancer Causes Control*, 16(4):437–47. doi:10.1007/s10552-004-5029-6 PMID:15953986

MacLeod JS, Harris MA, Tjepkema M, Peters PA, Demers PA (2017). Cancer risks among welders and occasional welders in a national population-based cohort study: Canadian Census Health and Environmental Cohort. *Saf Health Work*, 8(3):258–66. doi:10.1016/j.shaw.2016.12.001 PMID:28951802

Magnani C, Coggon D, Osmond C, Acheson ED (1987). Occupation and five cancers: a case-control study using death certificates. *Br J Ind Med*, 44(11):769–76. PMID:3689708

Mandel JS, McLaughlin JK, Schlehofer B, Mellemgaard A, Helmert U, Lindblad P, et al. (1995). International renal-cell cancer study. IV. Occupation. *Int J Cancer*, 61(5):601–5. doi:10.1002/ijc.2910610503 PMID:7768630

Mao Y, Hu J, Ugnat AM, White K; Canadian Cancer Registries Epidemiology Research Group (2000). Non-Hodgkin's lymphoma and occupational exposure to chemicals in Canada. *Ann Oncol*, 11:Suppl 1: 69–73. doi:10.1093/annonc/11.suppl_1.S69 PMID:10707783

Matos E, Vilensky MV, Boffetta PB (1998). Environmental and occupational cancer in Argentina: a case-control lung cancer study. *Cad Saude Publica*, 14:Suppl 3: 77–86. doi:10.1590/S0102-311X1998000700008 PMID:9819466

Matrat M, Guida F, Mattei F, Cénée S, Cyr D, Févotte J, et al.; Icare Study Group (2016). Welding, a risk factor of lung cancer: the ICARE study. *Occup Environ Med*, 73(4):254–61. doi:10.1136/oemed-2015-102964 PMID:26865654

Mattioli S, Truffelli D, Baldasseroni A, Risi A, Marchesini B, Giacomini C, et al. (2002). Occupational risk factors for renal cell cancer: a case–control study in northern Italy. *J Occup Environ Med*, 44(11):1028–36. doi:10.1097/00043764-200211000-00009 PMID:12448354

McCredie M, Stewart JH (1993). Risk factors for kidney cancer in New South Wales. IV. Occupation. *Br J Ind Med*, 50(4):349–54. PMID:8494775

McLaughlin JK, Malker HSR, Blot WJ, Malker BK, Stone BJ, Weiner JA, et al. (1987). Occupational risks for intracranial gliomas in Sweden. *J Natl Cancer Inst*, 78(2):253–7. PMID:3468289

McMillan GHG, Pethybridge RJ (1983). The health of welders in naval dockyards: proportional mortality study of welders and two control groups. *J Soc Occup Med*, 33(2):75–84. doi:10.1093/occmed/33.2.75 PMID:6865346

Meguellati-Hakkas D, Cyr D, Stücker I, Févotte J, Pilorget C, Luce D, et al. (2006). Lung cancer mortality and occupational exposure to asbestos among telephone linemen: a historical cohort study in France. *J Occup Environ Med*, 48(11):1166–72. doi:10.1097/01.jom.0000243357.70143.47 PMID:17099453

Melkild A, Langård S, Andersen A, Tønnessen JN (1989). Incidence of cancer among welders and other workers in a Norwegian shipyard. *Scand J Work Environ Health*, 15(6):387–94. doi:10.5271/sjweh.1834 PMID:2617255

Menck HR, Henderson BE (1976). Occupational differences in rates of lung cancer. *J Occup Med*, 18(12):797–801. doi:10.1097/00043764-197612000-00005 PMID:993873

Merletti F, Boffetta P, Ferro G, Pisani P, Terracini B (1991). Occupation and cancer of the oral cavity or oropharynx in Turin, Italy. *Scand J Work Environ Health*, 17(4):248–54. doi:10.5271/sjweh.1706 PMID:1925436

Merlo F, Costantini M, Doria M (1989). Cause specific mortality among workers exposed to welding fumes and gases: a historical prospective study. *J UOEH*, 11:Suppl: 302–15. PMID:2749060

Milatou-Smith R, Gustavsson A, Sjögren B (1997). Mortality among Welders Exposed to High and to Low Levels of Hexavalent Chromium and Followed for More Than 20 Years. *Int J Occup Environ Health*, 3(2):128–31. doi:10.1179/107735297800407749 PMID:9891110

Monárrez-Espino J, Stang A, Bromen K, Merzenich H, Anastassiou G, Jöckel KH (2002). Occupation as a risk factor for uveal melanoma in Germany. *Scand J Work Environ Health*, 28(4):270–7. doi:10.5271/sjweh.675 PMID:12199429

Morabia A, Markowitz S, Garibaldi K, Wynder EL (1992). Lung cancer and occupation: results of a multicentre case-control study. *Br J Ind Med*, 49(10):721–7. PMID:1419861

Moulin JJ, Wild P, Haguenoer JM, Faucon D, De Gaudemaris R, Mur JM, et al. (1993). A mortality study among mild steel and stainless steel welders. *Br J Ind Med*, 50(3):234–43. PMID:8457490

Neasham D, Sifi A, Nielsen KR, Overvad K, Raaschou-Nielsen O, Tjønneland A, et al. (2011). Occupation and risk of lymphoma: a multicentre prospective cohort study (EPIC). *Occup Environ Med*, 68(1):77–81. doi:10.1136/oem.2009.048173 PMID:20884795

Newhouse ML, Oakes D, Woolley AJ (1985). Mortality of welders and other craftsmen at a shipyard in NE England. *Br J Ind Med*, 42(6):406–10. PMID:4005194

NIOSH (2015). National Occupational Mortality Surveillance (NOMS). Available from: https://www.cdc.gov/niosh/topics/NOMS/chart2.html

Norell S, Ahlbom A, Olin R, Erwald R, Jacobson G, Lindberg-Navier I, et al. (1986). Occupational factors and pancreatic cancer. *Br J Ind Med*, 43(11):775–8. PMID:3790458

Office of Population Censuses and Surveys (1978). Occupational mortality. The Registrar General's decennial supplement for England and Wales, 1970–72. London, UK: Her Majesty's Stationery Office; p. 140.

Olsen J, Sabroe S, Lajer M (1984). Welding and cancer of the larynx: a case-control study. *Eur J Cancer Clin Oncol*, 20(5):639–43. doi:10.1016/0277-5379(84)90010-5 PMID:6539700

Olshan AF, Breslow NE, Daling JR, Falletta JM, Grufferman S, Robison LL, et al. (1990). Wilms' tumor and paternal occupation. *Cancer Res*, 50(11):3212–7. PMID:2159375

Olshan AF, De Roos AJ, Teschke K, Neglia JP, Stram DO, Pollock BH, et al. (1999). Neuroblastoma and parental occupation. *Cancer Causes Control*, 10(6):539–49. doi:10.1023/A:1008998925889 PMID:10616823

Oppenheimer M, Preston-Martin S (2002). Adult onset acute myelogenous leukemia and electromagnetic fields in Los Angeles County: bed-heating and occupational exposures. *Bioelectromagnetics*, 23(6):411–5. doi:10.1002/bem.10031 PMID:12210558

Paget-Bailly S, Guida F, Carton M, Menvielle G, Radoï L, Cyr D, et al. (2013). Occupation and head and neck cancer risk in men: results from the ICARE study, a French population-based case-control study. *J Occup Environ Med*, 55(9):1065–73. doi:10.1097/JOM.0b013e318298fae4 PMID:23969505

Pan SY, Ugnat AM, Mao Y; Canadian Cancer Registries Epidemiology Research Group (2005). Occupational risk factors for brain cancer in Canada. *J Occup Environ Med*, 47(7):704–17. doi:10.1097/01.jom.0000165747.95801.c5 PMID:16010197

Pannett B, Coggon D, Acheson ED (1985). A job-exposure matrix for use in population based studies in England and Wales. *Br J Ind Med*, 42(11):777–83. PMID:4063222

Parent ME, Hua Y, Siemiatycki J (2000). Occupational risk factors for renal cell carcinoma in Montreal. *Am J Ind Med*, 38(6):609–18. doi:10.1002/1097-0274(200012)38:6<609::AID-AJIM1>3.0.CO;2-4 PMID:11071683

Paris C, Clement-Duchene C, Vignaud JM, Gislard A, Stoufflet A, Bertrand O, et al. (2010). Relationships between lung adenocarcinoma and gender, age, smoking and occupational risk factors: A case-case study. *Lung Cancer*, 68(2):146–53. doi:10.1016/j.lungcan.2009.06.007 PMID:19586681

Park R, Krebs J, Mirer F (1994). Mortality at an automotive stamping and assembly complex. *Am J Ind Med*, 26(4):449–63. doi:10.1002/ajim.4700260403 PMID:7810544

Persson B, Dahlander AM, Fredriksson M, Brage HN, Ohlson CG, Axelson O (1989). Malignant lymphomas and occupational exposures. *Br J Ind Med*, 46(8):516–20. PMID:2775671

Persson B, Fredriksson M, Olsen K, Boeryd B, Axelson O (1993). Some occupational exposures as risk factors for malignant lymphomas. *Cancer*, 72(5):1773–8. doi:10.1002/1097-0142(19930901)72:5<1773::AID-CNCR2820720542>3.0.CO;2-6 PMID:8348507

Pesch B, Gawrych K, Rabstein S, Weiss T, Casjens S, Rihs HP, et al. (2013). N-acetyltransferase 2 phenotype, occupation, and bladder cancer risk: results from the EPIC cohort. *Cancer Epidemiol Biomarkers Prev*, 22(11):2055–65. doi:10.1158/1055-9965.EPI-13-0119-T PMID:24092628

Pesch B, Haerting J, Ranft U, Klimpel A, Oelschlägel B, Schill W (2000). Occupational risk factors for renal cell carcinoma: agent-specific results from a case-control study in Germany. MURC Study Group. Multicenter urothelial and renal cancer study. *Int J Epidemiol*, 29(6):1014–24. doi:10.1093/ije/29.6.1014 PMID:11101542

Pezzotto SM, Poletto L (1999). Occupation and histopathology of lung cancer: A case-control study in Rosario, Argentina. *Am J Ind Med*, 36(4):437–43. doi:10.1002/(SICI)1097-0274(199910)36:4<437::AID-AJIM4>3.0.CO;2-C PMID:10470008

Polednak AP (1981). Mortality among welders, including a group exposed to nickel oxides. *Arch Environ Health*, 36(5):235–42. doi:10.1080/00039896.1981.10667630 PMID:7294887

Porru S, Aulenti V, Donato F, Boffetta P, Fazioli R, Cosciani Cunico S, et al. (1996). Bladder cancer and occupation: a case-control study in northern Italy. *Occup Environ Med*, 53(1):6–10. doi:10.1136/oem.53.1.6 PMID:8563860

Preston-Martin S, Peters JM (1988). Prior employment as a welder associated with the development of chronic myeloid leukaemia. *Br J Cancer*, 58(1):105–8. doi:10.1038/bjc.1988.173 PMID:3166887

Pukkala E, Martinsen JI, Lynge E, Gunnarsdottir HK, Sparén P, Tryggvadottir L, et al. (2009). Occupation and cancer - follow-up of 15 million people in five Nordic countries. *Acta Oncol*, 48(5):646–790. doi:10.1080/02841860902913546 PMID:19925375

Puntoni R, Merlo F, Borsa L, Reggiardo G, Garrone E, Ceppi M (2001). A historical cohort mortality study among shipyard workers in Genoa, Italy. *Am J Ind Med*, 40(4):363–70. doi:10.1002/ajim.1110 PMID:11598985

Puntoni R, Vercelli M, Merlo F, Valerio F, Santi L (1979). Mortality among shipyard workers in Genoa, Italy. *Ann N Y Acad Sci*, 330(1):353–77. doi:10.1111/j.1749-6632.1979.tb18738.x PMID:230774

Reulen RC, Kellen E, Buntinx F, Brinkman M, Zeegers MP (2008). A meta-analysis on the association between bladder cancer and occupation. *Scand J Urol Nephrol Suppl*, 42(218):64–78. doi:10.1080/03008880802325192 PMID:18815919

Richiardi L, Boffetta P, Simonato L, Forastiere F, Zambon P, Fortes C, et al. (2004). Occupational risk factors for lung cancer in men and women: a population-based case-control study in Italy. *Cancer Causes Control*, 15(3):285–94. doi:10.1023/B:CACO.0000024223.91059.ed PMID:15090723

Rinsky RA, Melius JM, Hornung RW, Zumwalde RD, Waxweiler RJ, Landrigan PJ, et al. (1988). Case-control study of lung cancer in civilian employees at the Portsmouth Naval Shipyard, Kittery, Maine. *Am J Epidemiol*, 127(1):55–64. doi:10.1093/oxfordjournals.aje.a114791 PMID:3337077

Risch HA, Burch JD, Miller AB, Hill GB, Steele R, Howe GR (1988). Occupational factors and the incidence of cancer of the bladder in Canada. *Br J Ind Med*, 45(6):361–7. PMID:3395572

Rolland P, Gramond C, Lacourt A, Astoul P, Chamming's S, Ducamp S, et al.; PNSM Study Group (2010). Occupations and industries in France at high risk for pleural mesothelioma: A population-based case-control study (1998-2002). *Am J Ind Med*, 53(12):1207–19. doi:10.1002/ajim.20895 PMID:20886529

Ronco G, Ciccone G, Mirabelli D, Troia B, Vineis P (1988). Occupation and lung cancer in two industrialized areas of northern Italy. *Int J Cancer*, 41(3):354–8. doi:10.1002/ijc.2910410306 PMID:3346099

Ruder AM, Waters MA, Carreón T, Butler MA, Calvert GM, Davis-King KE, et al.; Brain Cancer Collaborative Study Group(2012). The Upper Midwest Health Study: industry and occupation of glioma cases and controls. *Am J Ind Med*, 55(9):747–55. doi:10.1002/ajim.22085 PMID:22715102

Saberi Hosnijeh F, Christopher Y, Peeters P, Romieu I, Xun W, Riboli E, et al. (2013). Occupation and risk of lymphoid and myeloid leukaemia in the European Prospective Investigation into Cancer and Nutrition (EPIC). *Occup Environ Med*, 70(7):464–70. doi:10.1136/oemed-2012-101135 PMID:23576671

Sadetzki S, Chetrit A, Turner MC, van Tongeren M, Benke G, Figuerola J, et al. (2016). Occupational exposure to metals and risk of meningioma: a multinational case-control study. *J Neurooncol*, 130(3):505–15. doi:10.1007/s11060-016-2244-4 PMID:27664150

Samanic CM, Kogevinas M, Silverman DT, Tardón A, Serra C, Malats N, et al. (2008). Occupation and bladder cancer in a hospital-based case-control study in Spain. *Occup Environ Med*, 65(5):347–53. doi:10.1136/oem.2007.035816 PMID:17951336

Sauvé JF, Lavoué J, Parent ME (2016). Occupation, industry, and the risk of prostate cancer: a case-control study in Montréal, Canada. *Environ Health*, 15(1):100 doi:10.1186/s12940-016-0185-1 PMID:27769264

Schifflers E, Jamart J, Renard V (1987). Tobacco and occupation as risk factors in bladder cancer: a case-control study in southern Belgium. *Int J Cancer*, 39(3):287–92. doi:10.1002/ijc.2910390304 PMID:3818120

Schoenberg JB, Stemhagen A, Mason TJ, Patterson J, Bill J, Altman R (1987). Occupation and lung cancer risk among New Jersey white males. *J Natl Cancer Inst*, 79(1):13–21. PMID:3474440

Seddon JM, Gragoudas ES, Glynn RJ, Egan KM, Albert DM, Blitzer PH (1990). Host factors, UV radiation, and risk of uveal melanoma. A case-control study. *Arch Ophthalmol*, 108(9):1274–80. doi:10.1001/archopht.1990.01070110090031 PMID:2400347

Seel EA, Zaebst DD, Hein MJ, Liu J, Nowlin SJ, Chen P (2007). Inter-rater agreement for a retrospective exposure assessment of asbestos, chromium, nickel and welding fumes in a study of lung cancer and ionizing radiation. *Ann Occup Hyg*, 51(7):601–10. PMID:17846032

Shah CP, Weis E, Lajous M, Shields JA, Shields CL (2005). Intermittent and chronic ultraviolet light exposure and uveal melanoma: a meta-analysis. *Ophthalmology*, 112(9):1599–607. doi:10.1016/j.ophtha.2005.04.020 PMID:16051363

Shangina O, Brennan P, Szeszenia-Dabrowska N, Mates D, Fabiánová E, Fletcher T, et al. (2006). Occupational exposure and laryngeal and hypopharyngeal cancer risk in central and eastern Europe. *Am J Epidemiol*, 164(4):367–75. doi:10.1093/aje/kwj208 PMID:16801374

Siemiatycki J (1991). Risk factors for cancer in the workplace. Boca Raton (FL), USA: CRC Press.

Siew SS, Kauppinen T, Kyyrönen P, Heikkilä P, Pukkala E (2008). Exposure to iron and welding fumes and the risk of lung cancer. *Scand J Work Environ Health*, 34(6):444–50. doi:10.5271/sjweh.1296 PMID:19137206

Silverman DT, Hoover RN, Albert S, Graff KM (1983). Occupation and cancer of the lower urinary tract in Detroit. *J Natl Cancer Inst*, 70(2):237–45. PMID:6571931

Silverman DT, Levin LI, Hoover RN (1989a). Occupational risks of bladder cancer in the United States: II Nonwhite men. *J Natl Cancer Inst*, 81(19):1480–3. doi:10.1093/jnci/81.19.1480 PMID:2778835

Silverman DT, Levin LI, Hoover RN (1990). Occupational risks of bladder cancer among white women in the United States. *Am J Epidemiol*, 132(3):453–61. doi:10.1093/oxfordjournals.aje.a115680 PMID:2389750

Silverman DT, Levin LI, Hoover RN, Hartge P (1989b). Occupational risks of bladder cancer in the United States: I. White men. *J Natl Cancer Inst*, 81(19):1472–80. doi:10.1093/jnci/81.19.1472 PMID:2778834

Silverstein M, Maizlish N, Park R, Mirer F (1985). Mortality among workers exposed to coal tar pitch volatiles and welding emissions: an exercise in epidemiologic triage. *Am J Public Health*, 75(11):1283–7. doi:10.2105/AJPH.75.11.1283 PMID:4051064

Simonato L, Fletcher AC, Andersen A, Anderson K, Becker N, Chang-Claude J, et al. (1991). A historical prospective study of European stainless steel, mild steel, and shipyard welders. *Br J Ind Med*, 48(3):145–54. PMID:2015204

Sjögren B (1980). A retrospective cohort study of mortality among stainless steel welders. *Scand J Work Environ Health*, 6(3):197–200. doi:10.5271/sjweh.2616 PMID:6937824

Sjögren B, Carstensen J (1986). Cancer morbidity among Swedish welders and gas-cutters. In: Stern RM, Berlin A, Fletcher AC, Järvisalo J editors. Health hazards and biological effects of welding fumes and gases. Amsterdam: Excerpta Medica; pp. 461–3.

Sjögren B, Gustavsson A, Hedström L (1987). Mortality in two cohorts of welders exposed to high- and low-levels of hexavalent chromium. *Scand J Work Environ Health*, 13(3):247–51. doi:10.5271/sjweh.2056 PMID:3616554

Smulevich VB, Solionova LG, Belyakova SV (1999). Parental occupation and other factors and cancer risk in children: II. Occupational factors. *Int J Cancer*, 83(6):718–22. doi:10.1002/(SICI)1097-0215(19991210)83:6<718::AID-IJC3>3.0.CO;2-T PMID:10597184

Sorahan T, Cooke MA (1989). Cancer mortality in a cohort of United Kingdom steel foundry workers: 1946-85. *Br J Ind Med*, 46(2):74–81. PMID:2923828

Sorahan T, Faux AM, Cooke MA (1994). Mortality among a cohort of United Kingdom steel foundry workers with special reference to cancers of the stomach and lung, 1946-90. *Occup Environ Med*, 51(5):316–22. doi:10.1136/oem.51.5.316 PMID:8199681

Sørensen AR, Thulstrup AM, Hansen J, Ramlau-Hansen CH, Meersohn A, Skytthe A, et al. (2007). Risk of lung cancer according to mild steel and stainless steel welding. *Scand J Work Environ Health*, 33(5):379–86. doi:10.5271/sjweh.1157 PMID:17973064

Soskolne CL, Jhangri GS, Pagano G, Botte G, Di Cintio P, Claudio L, et al. (2007). Using established occupational respiratory cancer risk factors for assessing the internal validity in an unmatched case-control study in the Campania Region of Italy, 1988–1990. *Eur J Oncol*, 12:23–9.

Steenland K (2002). Ten-year update on mortality among mild-steel welders. *Scand J Work Environ Health*, 28(3):163–7. doi:10.5271/sjweh.660 PMID:12109555

Steenland K, Beaumont J, Elliot L (1991). Lung cancer in mild steel welders. *Am J Epidemiol*, 133(3):220–9. doi:10.1093/oxfordjournals.aje.a115866 PMID:2000839

Steenland K, Beaumont J, Hornung R (1986). The use of regression analyses in a cohort mortality study of welders. *J Chronic Dis*, 39(4):287–94. doi:10.1016/0021-9681(86)90050-0 PMID:3958115

Stern FB, Waxweiler RA, Beaumont JJ, Lee ST, Rinsky RA, Zumwalde RD, et al. (1986). A case-control study of leukemia at a naval nuclear shipyard. *Am J Epidemiol*, 123(6):980–92. doi:10.1093/oxfordjournals.aje.a114350 PMID:3458360

’t Mannetje A, Brennan P, Zaridze D, Szeszenia-Dabrowska N, Rudnai P, Lissowska J, et al. (2012). Welding and lung cancer in Central and Eastern Europe and the United Kingdom. *Am J Epidemiol*, 175(7):706–14. doi:10.1093/aje/kwr358 PMID:22343633

’t Mannetje A, De Roos AJ, Boffetta P, Vermeulen R, Benke G, Fritschi L, et al. (2016). Occupation and risk of non-Hodgkin lymphoma and its subtypes: a pooled analysis from the InterLymph Consortium. *Environ Health Perspect*, 124(4):396–405. PMID:26340796

’t Mannetje A, Dryson E, Walls C, McLean D, McKenzie F, Maule M, et al. (2008). High risk occupations for non-Hodgkin’s lymphoma in New Zealand: case-control study. *Occup Environ Med*, 65(5):354–63. doi:10.1136/oem.2007.035014 PMID:18032530

Teschke K, Morgan MS, Checkoway H, Franklin G, Spinelli JJ, van Belle G, et al. (1997). Surveillance of nasal and bladder cancer to locate sources of exposure to occupational carcinogens. *Occup Environ Med*, 54(6):443–51. doi:10.1136/oem.54.6.443 PMID:9245952

Togawa K, Le Cornet C, Feychting M, Tynes T, Pukkala E, Hansen J, et al. (2016). Parental occupational exposure to heavy metals and welding fumes and risk of testicular germ cell tumors in offspring: a registry-based case-control study. *Cancer Epidemiol Biomarkers Prev*, 25(10):1426–34. doi:10.1158/1055-9965.EPI-16-0328 PMID:27439405

Tola S, Kalliomäki PL, Pukkala E, Asp S, Korkala ML (1988). Incidence of cancer among welders, platers, machinists, and pipe fitters in shipyards and machine shops. *Br J Ind Med*, 45(4):209–18. PMID:3377996

Tse LA, Yu IT, Qiu H, Au JS, Wang XR (2012). Occupational risks and lung cancer burden for Chinese men: a population-based case-referent study. *Cancer Causes Control*, 23(1):121–31. doi:10.1007/s10552-011-9861-1 PMID:22037909

Tucker MA, Hartge P, Shields JA (1986). Epidemiology of intraocular melanoma. *Recent Results Cancer Res*, 102:159–65. doi:10.1007/978-3-642-82641-2_14 PMID:3738184

Tucker MA, Shields JA, Hartge P, Augsburger J, Hoover RN, Fraumeni JF Jr (1985). Sunlight exposure as risk factor for intraocular malignant melanoma. *N Engl J Med*, 313(13):789–92. doi:10.1056/NEJM198509263131305 PMID:4033707

Vajdic CM, Kricker A, Giblin M, McKenzie J, Aitken JF, Giles GG, et al. (2004). Artificial ultraviolet radiation and ocular melanoma in Australia. *Int J Cancer*, 112(5):896–900. doi:10.1002/ijc.20476 PMID:15386378

Vallières E, Pintos J, Lavoué J, Parent ME, Rachet B, Siemiatycki J (2012). Exposure to welding fumes increases lung cancer risk among light smokers but not among heavy smokers: evidence from two case-control studies in Montreal. *Cancer Med*, 1(1):47–58. doi:10.1002/cam4.6 PMID:23342253

van der Gulden JW, Kolk JJ, Verbeek AL (1995). Work environment and prostate cancer risk. *Prostate*, 27(5):250–7. doi:10.1002/pros.2990270504 PMID:7479392

van Loon AJ, Goldbohm RA, Kant IJ, Swaen GM, Kremer AM, van den Brandt PA (1997a). Socioeconomic status and lung cancer incidence in men in The Netherlands: is there a role for occupational exposure? *J Epidemiol Community Health*, 51(1):24–9. doi:10.1136/jech.51.1.24 PMID:9135784

van Loon AJ, Kant IJ, Swaen GM, Goldbohm RA, Kremer AM, van den Brandt PA (1997b). Occupational exposure to carcinogens and risk of lung cancer: results from The Netherlands cohort study. *Occup Environ Med*, 54(11):817–24. doi:10.1136/oem.54.11.817 PMID:9538355

Vaughan TL (1989). Occupation and squamous cell cancers of the pharynx and sinonasal cavity. *Am J Ind Med*, 16(5):493–510. doi:10.1002/ajim.4700160503 PMID:2589327

Veglia F, Vineis P, Overvad K, Boeing H, Bergmann M, Trichopoulou A, et al. (2007). Occupational exposures, environmental tobacco smoke, and lung cancer. *Epidemiology*, 18(6):769–75. doi:10.1097/EDE.0b013e318142c8a1 PMID:18062064

Verma DK, Julian JA, Roberts RS, Muir DC, Jadon N, Shaw DS (1992). Polycyclic aromatic hydrocarbons (PAHs): a possible cause of lung cancer mortality among nickel/copper smelter and refinery workers. *Am Ind Hyg Assoc J*, 53(5):317–24. doi:10.1080/15298669291359717 PMID:1609742

Walschaerts M, Muller A, Auger J, Bujan L, Guérin JF, Le Lannou D, et al. (2007). Environmental, occupational and familial risks for testicular cancer: a hospital-based case-control study. *Int J Androl*, 30(4):222–9. doi:10.1111/j.1365-2605.2007.00805.x PMID:17708752

Wilkins JR 3rd, Sinks TH Jr (1984). Paternal occupation and Wilms’ tumour in offspring. *J Epidemiol Community Health*, 38(1):7–11. doi:10.1136/jech.38.1.7 PMID:6323612

Wilkins JR 3rd, Wellage LC (1996). Brain tumor risk in offspring of men occupationally exposed to electric and magnetic fields. *Scand J Work Environ Health*, 22(5):339–45. doi:10.5271/sjweh.151 PMID:8923606

Wong JYY, Bassig BA, Seow WJ, Hu W, Ji BT, Blair A, et al. (2017). Lung cancer risk in welders and foundry workers with a history of heavy smoking in the USA: The National Lung Screening Trial. *Occup Environ Med*, 74(6):440–8. doi:10.1136/oemed-2016-104168 PMID:28069970

Wong O, Harris F, Armstrong TW, Hua F (2010). A hospital-based case-control study of acute myeloid leukemia in Shanghai: analysis of environmental and occupational risk factors by subtypes of the WHO classification. *Chem Biol Interact*, 184(1-2):112–28. doi:10.1016/j.cbi.2009.10.017 PMID:19900423

Wortley P, Vaughan TL, Davis S, Morgan MS, Thomas DB (1992). A case-control study of occupational risk factors for laryngeal cancer. *Br J Ind Med*, 49(12):837–44. PMID:1472441

Wu WT, Lu YH, Lin YJ, Yang YH, Shiue HS, Hsu JH, et al. (2013). Mortality among shipbreaking workers in Taiwan–a retrospective cohort study from 1985 to 2008. *Am J Ind Med*, 56(6):701–8. doi:10.1002/ajim.22135 PMID:23532723

Xie S-H, Yu IT, Tse LA, Au JSK, Lau JSM (2017). Occupational risk factors for nasopharyngeal carcinoma in Hong Kong Chinese: a case-referent study. *Int*

Arch Occup Environ Health, 90(5):443–9. doi:10.1007/s00420-017-1212-4 PMID:28255757

Yiin JH, Schubauer-Berigan MK, Silver SR, Daniels RD, Kinnes GM, Zaebst DD, et al. (2005). Risk of lung cancer and leukemia from exposure to ionizing radiation and potential confounders among workers at the Portsmouth Naval Shipyard. *Radiat Res*, 163(6):603–13. doi:10.1667/RR3373 PMID:15913392

Yiin JH, Silver SR, Daniels RD, Zaebst DD, Seel EA, Kubale TL (2007). A nested case-control study of lung cancer risk and ionizing radiation exposure at the portsmouth naval shipyard. *Radiat Res*, 168(3):341–8. doi:10.1667/RR0843.1 PMID:17705634

Zaebst DD, Seel EA, Yiin JH, Nowlin SJ, Chen P (2009). Summary of retrospective asbestos and welding fume exposure estimates for a nuclear naval shipyard and their correlation with radiation exposure estimates. *J Occup Environ Hyg*, 6(7):404–14. doi:10.1080/15459620902922573 PMID:19378213

Zahm SH, Brownson RC, Chang JC, Davis JR (1989). Study of lung cancer histologic types, occupation, and smoking in Missouri. *Am J Ind Med*, 15(5):565–78. doi:10.1002/ajim.4700150509 PMID:2741962

Zaridze DG, Nekrasova LI, Basieva TKh (1992). [Increased risk factors for the occurrence of bladder cancer] *Vopr Onkol*, 38(9):1066–73. [Russian] PMID:1300819

Zeegers MP, Friesema IH, Goldbohm RA, van den Brandt PA (2004). A prospective study of occupation and prostate cancer risk. *J Occup Environ Med*, 46(3):271–9. doi:10.1097/01.jom.0000116961.48464.6b PMID:15091290

Zheng T, Blair A, Zhang Y, Weisenburger DD, Zahm SH (2002). Occupation and risk of non-Hodgkin's lymphoma and chronic lymphocytic leukemia. *J Occup Environ Med*, 44(5):469–74. doi:10.1097/00043764-200205000-00015 PMID:12024692