

# The burden of occupational cancer in Great Britain

Lung cancer

Prepared by the **Health and Safety Laboratory**,  
the **Institute of Occupational Medicine** and  
**Imperial College London**  
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The aim of this project was to produce an updated estimate of the current burden of cancer for Great Britain resulting from occupational exposure to carcinogenic agents or exposure circumstances. The primary measure of the burden of cancer was the attributable fraction (AF) being the proportion of cases that would not have occurred in the absence of exposure; and the AF was used to estimate the number of attributable deaths and registrations. The study involved obtaining data on the risk of the cancer due to the exposure of interest, taking into account confounding factors and overlapping exposures, as well as the proportion of the target population exposed over the relevant exposure period. Only carcinogenic agents, or exposure circumstances, classified by the International Agency for Research on Cancer (IARC) as definite (Group 1) or probable (Group 2A) human carcinogens were considered. Here, we present estimates for cancer of the lung that have been derived using incidence data for calendar year 2004, and mortality data for calendar year 2005.

The estimated total (male and female) AF, deaths and registrations for lung cancer related to overall occupational exposure is 14.47% (95% Confidence Interval (CI)= 12.96-17.20), which equates to 4745 (95%CI= 4251-5643) attributable deaths and 5442 (95%CI=4877-6469) attributable registrations.

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## EXECUTIVE SUMMARY

The aim of this project was to produce an updated estimate of the current burden of cancer for Great Britain resulting from occupational exposure to carcinogenic agents or exposure circumstances. The primary measure of the burden of cancer used in this project was the attributable fraction i.e. the proportion of cases that would not have occurred in the absence of exposure; this was then used to estimate the attributable numbers. This involved obtaining data on the risk of the disease due to the exposure of interest, taking into account confounding factors and overlapping exposures, and the proportion of the target population exposed over the period in which relevant exposure occurred. Estimation was carried out for carcinogenic agents or exposure circumstances classified by the International Agency for Research on Cancer (IARC) as definite (Group 1) or probable (Group 2A) human carcinogens. Here, we present estimates for cancer of the lung that have been derived using incidence data for calendar year 2004, and mortality data for calendar year 2005.

Estimation has been carried out for lung cancer for 21 separate carcinogens or occupational circumstances. Those classified by IARC as a definite human carcinogens for lung cancer are: arsenic, asbestos, beryllium, cadmium, chromium, crystalline silica, environmental tobacco smoke (ETS), ionising radiation, mineral oils, nickel, polycyclic aromatic hydrocarbons (PAH), radon, strong inorganic mist containing sulphuric acid, dioxins (TCDD), tin mining, iron and steel founding and occupation as a painter. Those classified by IARC as a probable human carcinogen for lung cancer are: cobalt, diesel engine exhaust (DEE), inorganic lead and occupation as a welder. Estimation for several other occupational carcinogens or circumstances classified as a group 1 or 2A carcinogen has not been carried out because they are (a) included in the estimation for one of the 21 above, (b) numbers of those exposed in GB are extremely small or (c) the carcinogen was removed or the process ceased before the relevant period.

Arsenic exposure can occur in smelting, manufacture and use of arsenical pesticides, sheep-dip compounds, and wood preservatives and in the manufacture of glass and nonferrous alloys. Historical exposure to asbestos occurred in manufacture of, insulation, among cement workers, vermiculite workers, miners and millers, railroad car construction workers, shipyard workers, and asbestos textile workers. Current exposure occurs particularly in the construction industry. Beryllium exposure occurs mainly in mining, refining and in the manufacture of ceramics, and electronic and aerospace equipment. Cadmium is principally used in electroplating, in compounds that serve as stabilisers for plastics, as pigments, in electrodes in batteries, and in alloys. Worker exposure to chromium occurs in the production of stainless steel, other alloys, and chrome-containing pigments and during chrome-plating and welding. Occupational exposure to cobalt occurs predominantly during refining of cobalt, in the production of alloys, and in the manufacture and maintenance of hard-metal tools and the use of diamond-cobalt tools. Exposure to crystalline silica occurs in the industries such as construction, pottery, masonry and stonework, concrete and gypsum, foundries, brick making and in mining where the ore has high silica content. Exposure to DEE occurs in many occupations with professional drivers and motor mechanics being likely to be exposed to elevated levels. Exposure to ETS has occurred particularly in the wholesale and retail trade, restaurants and hotels, construction, financing and business. Occupational exposure to ionising radiation affects nuclear industry workers, disaster clean-up workers, radiologists, technologists, miners, aircrew and military personnel. Exposure to inorganic lead occurs in the manufacture of batteries, in lead smelting, printing and glass works. Mineral oils exposure, particularly oil mists, occur in metalworking, print press operating, and cotton and jute spinning. Worker exposure to nickel occurs in nickel refining, mining and smelting, production of nickel alloys, stainless steel and nickel-cadmium batteries and in welding of stainless steel. PAHs are formed by the incomplete combustion of carbon-containing fuels in a number of occupational settings including coal gasification, coke production, coal-tar distillation, chimney sweeping (soots), and in use

of coal tar and pitches, and creosotes. Very few workers in metal ore mining are exposed now to radon in GB; however, large numbers are exposed to radon through working in sites located in areas of high naturally occurring radon exposure. Workers exposure to strong inorganic acid mists can occur during production of isopropanol and ethanol, steel pickling, battery manufacture and sulphuric acid production, and manufacture of soaps and detergents. Occupational exposure to dioxins (TCDD) can occur in the pulp and paper industry, as a contaminant in the manufacturing process of certain chlorinated organic chemicals including pesticides, at metal recycling and landfill sites, during cement manufacture, and at municipal waste incinerators.

As very few workers have been exposed to mustard gas, bis(chloromethyl)ether, no estimation has been carried out for lung cancer. Also excluded for lung cancer are: coal tars and pitches, soots, coal gasification, coke production, aluminium production (included with the estimation for polycyclic aromatic hydrocarbons (PAH)); hairdressers and barbers (included with environmental tobacco smoke (ETS)); isopropyl alcohol manufacture (included with strong acids and very small numbers exposed), art glass (included with arsenic); non-arsenical insecticides (included with dioxins); talc containing asbestiform fibres (included with asbestos); epichlorohydrin (unknown number exposed); rubber industry (the british study shows no increased risk).

Due to assumptions made about cancer latency and working age range, only cancers in ages 25+ in 2005/2004 could be attributable to occupation. For Great Britain in 2005, there were 19045 total deaths in men aged 25+ and 13753 in women aged 25+ from lung cancer; in 2004 there were 21923 total registrations for lung cancer in men aged 25+ and 15455 in women aged 25+.

The estimated total (male and female) attributable fraction for lung cancer related to occupational exposure is 14.47% (95% Confidence Interval (CI)=12.96-17.20), which equates to 4745 (95%CI=4251-5643) attributable deaths and 5442 (95%CI=4877-6469) attributable registrations. Results for individual carcinogenic agents for which the attributable fraction was determined are as follows:

- **Arsenic:** The estimated total (male and female) attributable fraction is 0.34% (95%CI=0.13%-0.73%), which equates to 113 deaths (95%CI=43-240), and 129 registrations (95%CI=49-274).
- **Asbestos:** The estimated total (male and female) attributable fraction is 5.91% (95%CI=5.40%-6.40%), which equates to 1,937 (95%CI=1,770-2,100) deaths and 2,223 (95%CI=2,032-2,409) registrations.
- **Beryllium:** The estimated total (male and female) attributable fraction is 0.02% (95%CI= 0.00%-0.04%), which equates to 6 deaths (95%CI=0-14), and 7 (95%CI=0-16) registrations.
- **Cadmium:** The estimated total (male and female) attributable fraction is 0.02% (95%CI= 0.01%-0.04%), which equates to 8 (95%CI=4-12) deaths and 9 (95%CI=4-14) registrations.
- **Chromium:** The estimated total (male and female) attributable fraction is 0.18% (95%CI = 0.12%-0.25%), which equates to 58 (95%CI=38-81) deaths and 67 (95%CI=44-92) registrations
- **Cobalt:** The estimated total (male and female) attributable fraction is 0.19% (95%CI=0.05%-0.39%), which equates to 63 deaths (95%CI=16-128), and 73 (95%CI=18-147) registrations.
- **Crystalline silica:** The estimated total (male and female) attributable fraction is 2.41% (95%CI=1.80%-3.04%), which equates to 789 (95%CI=592-998) deaths and 907 (95%CI= 680-1,147) registrations.
- **DEE:** The estimated total (male and female) attributable fraction is 1.84% (95%CI=0.00%-3.37%), which equates to 605 (95%CI=272-1,107) deaths and 695 (95%CI=313-1,269) registrations
- **ETS:** The estimated total (male and female) attributable fraction is 0.76% (95%CI=0.08%-1.75%), which equates to 249 (95%CI=27-574) deaths and 284 (95%CI=30-655) registrations

- **Ionising Radiation:** The estimated total (male and female) attributable fraction is 0.01% (95%CI not available), which equates to 2 deaths and 2 registrations.
- **Inorganic Lead:** The estimated total (male and female) attributable fraction is 0.11% (95%CI=0.00%-0.40%), which equates to 36 (95%CI=0-130) deaths and 41 (95%CI=0-149) registrations
- **Mineral oils:** The estimated total (male and female) attributable fraction is 1.25% (95%CI= 0.44%-2.14%), which equates to 410 (95%CI=146-701) deaths and 470 (95%CI=167-804) registrations.
- **Nickel:** The estimated total (male and female) attributable fraction is 0.02% (95%CI= 0.00%-0.08%), which equates to 8 deaths (95%CI=0-25), and 9 (95%CI=0-29) registrations.
- **PAHs:** The estimated total (male and female) attributable fraction is 0.003% (95%CI=0.001%-0.003%), which equates to 1 (95%CI=0-1) death and 1 (95%CI=0-1) registration.
- **Radon:** The estimated total (male and female) attributable fraction is 0.56% (95%CI= 0.28%-0.84%), which equates to 184 (95%CI=92-276) deaths and 209 (95%CI=105-314) registrations.
- **Strong inorganic acid mists:** The estimated total (male and female) attributable fraction is 0.20% (95%CI=0.00%-0.55%), which equates to 67 (95%CI=0-181) deaths and 76 (95%CI=0-207) registrations.
- **TCDD (Dioxins):** The estimated total (male and female) attributable fraction is 0.57% (95%CI=0.00%-1.49%), which equates to 187 (95%CI=0-488) deaths and 215 (95%CI= 0-559) registrations.
- **Tin mining (men only):** The estimated total (male and female) attributable fraction is 0.002% (95%CI=0.001%-0.003%), which equates to 1 (95%CI=0-1) deaths and 1 (95%CI= 0-1) registrations.
- **Iron and Steel founding:** The estimated total (male and female) attributable fraction is 0.08% (95%CI=0.06%-0.10%), which equates to 25 (95%CI=19-32) deaths and 29 (95%CI= 22-37) registrations.
- **Work as a painter:** The estimated total (male and female) attributable fraction is 0.75% (95%CI=0.43%-1.10%), which equates to 246 (95%CI=140-360) deaths and 282 (95%CI= 161-413) registrations.
- **Work as a welder:** The estimated total (male and female) attributable fraction is 0.46% (95%CI=0.36%-0.57%), which equates to 152 (95%CI=118-188) deaths and 175 (95%CI= 135-216) registrations.



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# 1 INCIDENCE AND TRENDS

Lung cancer (ICD-10 C33/C34; ICD-9 162) was a rare disease until the early part of the 20<sup>th</sup> century, but has become the most common malignant neoplasm among men in most countries, and a parallel increase in incidence is now seen among women, notably in western countries. In 2003, lung cancer accounted for an estimated 17,549 new cases each year among men, in the UK, i.e. about 15.5% of all cancers excluding skin cancer, and 12,253 that are 10.7%, of new cases among women<sup>1</sup>. After non-melanoma skin cancer, it is the most frequent malignant neoplasm in humans and the most important cause of death from neoplasia. Lung cancer has always been amongst the top three neoplasms in the UK. The others with the highest number of registrations are prostate (23.8%) and colorectal (13.5%) for men; and for women they are breast (31.8%) and colorectal (11.0%) (Table 1). In men lung cancer was the most commonly registered neoplasm up until 1999. In Scotland the same cancers make up the bulk of the registrations in men, but lung cancer is still the highest amongst men. Approximately 42% of all cases occur in developing countries (Parkin *et al*, 1999). The geographic and temporal patterns are determined chiefly by the consumption of tobacco (Boffetta and Trichopoulos, 2002). An increase in tobacco consumption is paralleled some 20 years later by an increase in the incidence of lung cancer, and a decrease in consumption is followed by a decrease in incidence. Other factors, such as genetic susceptibility, poor diet, and indoor air pollution, may act in conjunction with tobacco smoking in shaping the descriptive epidemiology of lung cancer.

Among both men and women, the incidence is low in individuals aged less than 40 years and increases up to age 70 or 75 (Quinn *et al*, 2001). Thereafter, there is a decline that can be explained, at least in part, by incomplete diagnosis or by a birth-cohort effect.

In developed countries, the risk of lung cancer among men is regularly two to three times higher in lower than higher socio-economic classes (Quinn *et al*, 2005). The evidence from developing countries is sparse but studies from Colombia and Brazil suggest an opposite trend (Faggiano *et al*, 1997).

Lung cancer is highly fatal, so the trends in incidence and mortality are closely similar (Tables 2 and 3). Survival in 1986-90 was very poor, only around 20% after one year and 5% after five years in both men and women (Quinn *et al*, 2005). In men in England, Wales and Scotland, both incidence and mortality reached a plateau in the early 1970s and both have since steadily fallen. However, in women increasing trends were seen up to the end of the 1980s, since when rates have been fairly stable. Lung cancer accounted for 28% of cancer deaths, and 24% of such deaths in females in 2004<sup>2</sup>.

**Table 1** Most common cancers registered in the UK, 2003 <sup>3</sup>(percentage).

Cancer	Men		Women	
	England & Wales	Scotland	England & Wales	Scotland
Prostate	23.8	18.4	---	---
Lung	15.5	20.5	10.7	15.0
Colorectal	13.5	14.2	11.0	11.9
Breast	---	---	31.8	27.5

<sup>1</sup> [http://www.statistics.gov.uk/downloads/theme\\_health/Dh2\\_30/DH2No30.pdf](http://www.statistics.gov.uk/downloads/theme_health/Dh2_30/DH2No30.pdf)

<sup>2</sup> [http://www.statistics.gov.uk/downloads/theme\\_health/Dh2\\_31/DH2No31.pdf](http://www.statistics.gov.uk/downloads/theme_health/Dh2_31/DH2No31.pdf)

<sup>3</sup> [http://www.statistics.gov.uk/downloads/theme\\_health/MB1\\_34/MB1\\_34.pdf](http://www.statistics.gov.uk/downloads/theme_health/MB1_34/MB1_34.pdf)

**Table 2** UK Lung cancer registration trends in England (1994 = England and Wales; excluding non-melanoma skin cancer)<sup>4</sup>.

Year	Males				Females			
	Total Registrations	Cancer Registrations	% Total	Rate /100000	Total	Cancer Registrations	% Total	Rate /100000
1994	112,145	23,314	20.8	92.1	112,175	12,297	11.0	46.7
1995	103,986	21,060	20.3	87.7	105,151	11,668	11.1	46.9
1996	104,103	20,047	19.3	83.1	105,461	11,349	10.8	45.5
1997	104,335	19,846	19.0	81.8	107,289	11,439	10.7	45.7
1998	106,745	19,515	18.3	80.1	109,957	11,812	10.7	47.0
1999	108,827	19,283	17.7	78.6	112,237	11,854	10.6	47.0
2000	111,543	19,035	17.1	79.9	112,066	12,055	10.8	47.9
2001	112,516	18,577	16.5	76.9	112,134	11,963	10.7	47.4
2002	112,579	18,056	16.0	74.3	111,210	11,922	10.7	47.0
2003	112,732	17,549	15.6	71.9	114,740	12,253	10.7	48.2
2004	117,805	18,105	15.4	73.7	110,840	12,354	11.1	48.4
<b>Average</b>	<b>109,756</b>	<b>19,490</b>	<b>17.8</b>	<b>80.0</b>	<b>110,296</b>	<b>11,906</b>	<b>10.8</b>	<b>47.1</b>

**Table 3** Lung cancer mortality trends in England and Wales (excluding non-melanoma skin cancer).<sup>5</sup>

Year	Males				Females			
	Total Deaths (UK)	Lung Cancer Deaths, UK	% Total	Lung Cancer Death Rate, UK (/100000)	Total Deaths (UK)	Lung Cancer Deaths, UK	% Total	Lung Cancer Death Rate, UK (/100000)
1971-75	294,957	25,897	8.8	106.6	291,936	6,209	2.1	18.3
1976-80	295,013	26,732	9.1		290,737	7,624	2.6	
1981-85	359,493	26,159	7.3	100.4	320,635	9,173	2.9	27.1
1986-90	374,103	24,457	6.5		343,106	10,474	3.1	29.4
1991-95	374,029	28,546	7.6	90.5	342,716	10,992	3.2	29.4
1998	300,160	19,363	6.5	75.0	329,012	11,589	3.5	43.6
1999	264,299	18,736	7.1	68.0	291,819	11,232	3.8	42.2
2000	255,347	17,993	7.0	65.9	280,117	11,120	4.0	41.6
2001	252,426	17,579	7.0	63.5	277,947	11,149	4.0	41.9
2002	253,144	17,447	6.9	62.7	280,383	11,359	4.1	42.1
2003	253,852	17,155	6.8	53.8	284,402	11,610	4.1	28.5
2004	244,130	16,862	6.9	52.0	268,411	11,466	4.3	28.4
2005	242,057	16,852	7.0	51.3	268,408	11,940	4.4	29.0
<b>Average</b>	<b>289,462</b>	<b>21,060</b>	<b>7.3</b>	<b>71.8</b>	<b>297,664</b>	<b>10,457</b>	<b>3.5</b>	<b>33.5</b>

<sup>4</sup> <http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=8843&Pos=&ColRank=1&Rank=240>

<sup>5</sup> <http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=618>

## 2 OVERVIEW OF AETIOLOGY

### 2.1 INTRODUCTION

The overwhelming determinant of the occurrence of lung cancer is cigarette smoking, which is now estimated to account for approximately 90% of the burden in developed countries (Peto *et al*, 1994), either independently or via synergistic associations with other risk factors. Therefore the effects of occupational hazards may be difficult to determine because of the strong confounding effects of smoking, and because many hazards only effect a small number of the relevant job groups. The important role of specific occupational exposures in the aetiology of lung cancer is well established in reports dating back to the 1950s (Boffetta and Trichopoulos, 2002). The risk of lung cancer is increased among workers in a number of industries and occupations. The responsible agent(s) have been identified for several, but not all, of these high-risk workplaces. IARC have assessed the carcinogenicity of a number of substances and occupational circumstances with those classified as Group 1 having sufficient evidence in humans and those classified as Group 2A having limited evidence in humans. Those classified as causing lung cancer are given in Table 4. Siemiatycki *et al*. (2004) summarise the evidence used in the classification of these agents and substances as strong or suggestive and this is also given in Table 4. A number of other chemicals and occupations/industries, not classified as a Group 1/2A lung carcinogen, include lead, acrylonitrile, formaldehyde, vinyl chloride, welding, manufacture of boots and shoes and the wood industry.

The Occupational Health Decennial Supplement (Drever, 1995) reports for different occupational groups mortality (1979-1980, 1982-1990) and cancer incidence (1981-1987) in men and women aged 20-74 years in England and Wales. For many diseases differences in mortality between job groups appeared to be determined mainly by non-occupational influences. Occupations that had a high proportional mortality rate (PMR) for lung cancer generally entailed exposure to known lung carcinogens (Table 5). Electroplaters who are exposed to chromates (PMR: men - 126, 95%CI=105-149; women - 273, 95%CI=100-594), and labourers in coke ovens who have high exposure to Polycyclic Aromatic Hydrocarbons (PAHs) (PMR: men - 118, 95%CI=110-138), both had significantly increased PMRs. Several occupations had statistically significant proportional rate ratios (PRR) for lung cancer that could be related to exposures, including moulders and coremakers (metals), other metal manufacturers, metal polishers, fettlers and dressers (metals), welders, other spray painters, painters and decorators, bricklayers and tilers, construction workers and boiler operators. Whilst some of these excesses may be related to possible exposures they represent only small increases in risk based on large numbers of cases.

In the 1971 decennial supplement, which examined mortality around 1961, lung cancer was high in the following occupations: glass and ceramics makers; furnace, forge, foundry, rolling mill workers; construction workers; painters and decorators; warehousemen, storekeepers, packers, bottlers; service, sport and recreation workers; members of the Armed Forces; engineering and allied trades workers; food, drink and tobacco workers; labourers; and transport and communication workers.

**Table 4** Occupational agents, groups of agents, mixtures, and exposure circumstances classified by the IARC Monographs, Vols 1-77 (IARC, 1972-2001), into Groups 1 and 2A, which have the lung as the target organ.

Agents, Mixture, Circumstance	Main industry, Use	Evidence of carcinogenicity in humans*	Strength of evidence <sup>§</sup>	Other target organs
<b>Group 1: Carcinogenic to Humans</b>				
<b>Agents, groups of agents</b>				
Arsenic & arsenic compounds	Glass, metals, pesticides	Sufficient	Strong	Skin, Liver (angiosarcoma)
Asbestos	Asbestos product manufacturing, installation and use of products, particularly in construction, asbestos removal and stripping	Sufficient	Strong	Pleura
Beryllium	Aerospace	Sufficient	Strong	
Bis(chloromethyl)ether & chloromethyl methyl ether	Chemical intermediate	Sufficient	Strong	
Cadmium & cadmium compounds	Dye/pigment	Sufficient	Strong	
Chromium (VI) compounds	Metal plating, dye/pigment	Sufficient	Strong	Nose
Environmental tobacco smoke	Office, bar, restaurant workers	Sufficient	Strong	
Ionising radiation	Medical, nuclear, aircraft crew	Sufficient	Strong	Many
Mineral oils	Metal workers, machinists, engineers	Sufficient	Strong	Skin, Bladder, Sinonasal
Mustard gas	Production; used in research laboratories; military personnel	Sufficient	Suggestive	Larynx Pharynx
Nickel compounds	Metallurgy, alloy, catalyst	Sufficient	Strong	Nose
Polycyclic aromatic hydrocarbons: Benzo(a)pyrene	Work involving combustion of organic matter; foundries; steel mills; fire-fighters; vehicle mechanics		Suggestive	Bladder Skin
Coal-tar and pitches	Construction, electrodes, fuels	Sufficient	Suggestive	Skin, Bladder
Soots	Chimney sweeps, work involving burning organic materials	Sufficient	Strong	Skin
Radon & its decay products	Mining	Sufficient	Strong	
Crystalline silica	Stone cutting, mining, glass, paper	Sufficient	Strong	
Strong inorganic-acid mists containing sulphuric acid	Pickling operations, steel, petrochemical industries, phosphate acid fertiliser manufacturing	Sufficient	Suggestive	Larynx
Talc containing asbestiform fibres	Paper, paints	Sufficient	Strong	
TCDD (dioxin)	Production; use of chlorophenols & chlorophenoxy herbicides; waste incineration; PCB production; pulp & paper bleaching	Limited	Suggestive	All sites, Non-Hodgkin's Lymphoma, Sarcomas
<b>Exposure circumstances</b>				
Aluminium production		Sufficient	Strong	Bladder
Coal gasification		Sufficient	Strong	Skin, Bladder

**Table 4** Occupational agents, groups of agents, mixtures, and exposure circumstances classified by the IARC Monographs, Vols 1-77 (IARC, 1972-2001), into Groups 1 and 2A, which have the lung as the target organ.

Agents, Mixture, Circumstance	Main industry, Use	Evidence of carcinogenicity in humans*	Strength of evidence <sup>§</sup>	Other target organs
Coke production		Sufficient	Strong	Skin, Bladder, Kidney
Hematite mining (underground) with exposure to radon		Sufficient	Strong	
Iron & steel founding		Sufficient	Strong	
Painter (occupational exposure)		Sufficient	Strong	
<b>Group 2A: Probably Carcinogenic to Humans</b>				
<b>Agents &amp; groups of agents</b>				
$\alpha$ -Chlorinated toluenes & benzoyl chloride (combined exposure)	Chemical intermediate	Limited	Suggestive	
Cobalt metal with tungsten carbide	Production of cemented carbides (hard metal industry), tool grinders, saw filers, diamond polishers	Limited	Suggestive	
Diesel engine exhaust	Railroad workers, professional drivers, dock workers, mechanics	Limited	Suggestive	Bladder
Epichlorohydrin	Production and use of resins, glycerine and propylene based rubbers	Inadequate	Suggestive	CNS
Inorganic Lead	Lead smelters, plumbers, solderers, occupations in battery recycling smelters, production of lead-acid batteries, printing press occupations, pigment production, construction and demolition	Limited	Suggestive	Stomach
Non-arsenical insecticides (occupational exposures in spraying & application)	Production, pest control and agricultural workers, flour and grain mill workers	Limited	Suggestive	
PAHs Dibenz(a,h)anthracene Cyclopenta(cd)pyrene, Dibenzo(a,l)pyrene	Foundries, steel mills, fire-fighters, vehicle mechanics	Not available	Suggestive	
<b>Exposure circumstances</b>				
Art glass, glass containers, & pressed ware (manufacture)		Limited	Suggestive	
Hairdressers and barbers		Limited	Suggestive	
Isopropyl alcohol manufacture, strong acid process		Limited	Suggestive	Paranasal sinuses, Larynx
Rubber industry		Limited	Suggestive	Bladder, Stomach, Larynx, Leukaemia
<b>Group 2B: Possibly Carcinogenic to Humans</b>				
<b>Exposure circumstances</b>				
Welding fumes	Metal fabricating industry	Limited		

\* Evidence according to the IARC monograph evaluation; § taken from Siemiatycki *et al.* (2004)

**Table 5** Job codes with significantly high PRRs and PMRs for lung cancer. Men and women aged 20-74 years, England, 1981-87.

Job group		PRR	95%CI	PMR	95%CI
SIC code	Description				
<b>Men</b>					
012	Vocational trainers, social scientists, etc.	121	102-144		
029	Electrical and electronic engineers (professional)	124	100-154		
030	Professional engineers	125	115-136	123	117-129
038	Production and maintenance managers	108	101-118	107	103-111
040	Managers in transport, utilities and mining	120	111-131	115	110-120
044	Retailers and dealers	114	110-119	108	105-110
045	Publican and bar staff	122	115-131	129	123-134
056	Van sales persons	115	101-131		
064	Undertakers	136	101-180	123	101-148
088	Other coalminers	104	100-109	92	89-94
115	Metal drawers	130	100-166		
116	Moulders and coremakers (metals)	123	111-138	118	110-127
117	Electroplaters			126	105-149
120	Other metal manufacturers	111	102-122	112	105-119
126	Metal polishers	120	102-141	122	109-136
127	Fettlers and dressers (metal)	124	101-151	127	112-143
144	Plumbers and gas fitters			107	103-112
149	Welders			109	103-114
159	Other spray painters			126	116-137
160	Painters and decorators	108	103-144	112	109-116
164	Packers and sorters	111	101-123		
165	Bricklayers and tilesetters	107	101-114	112	107-117
167	Plasterers	115	103-129	127	119-136
169	Builders etc.			106	103-110
174	Constructions worker	114	109-122	114	110-118
179	Shunters and pointsmen	141	109-181		
183	Lorry drivers	107	104-111	109	107-112
187	Crane drivers	109	100-119		
193	Labourer in coke ovens			118	110-138
194	Boiler operators	114	104-127	115	108-123
<b>Women</b>					
012	Vocational trainers, social scientists, etc.	180	101-297		
044	Retailers and dealers	112	106-120		
045	Publicans and bar staff	138	124-156		
057	Sales representatives	165	124-216		
086	Plastic workers	306	123-631		
104	Carpenters	171	105-266		
124	Machine tool operators	129	105-159		
125	Press and automative machine operators	127	100-162		
126	Metal polishers	191	109-310		
174	Construction workers	269	154-437		

Source: (Drever 1995) Occupational Health Decennial Supplement

Table 6 gives PMRs for men and women that were significantly raised in men and women aged 16-74 years between 1991 and 2000 in the latest analysis of occupational mortality in GB (Coggon *et al*, 2009). A large number of these occupations are known to involve exposure to known lung carcinogens including asbestos, crystalline silica, and PAHs.

**Table 6** Job codes with significantly high PMRs for lung cancer. Men and women aged 15-74 years, England, 1991-2000.

Job group		PMR	95%CI
SIC code	Description		
<b>Men</b>			
023	Driving instructors (excluding HGV)	116	100-133
029	Electrical and electronic engineers (professional)	126	103-153
036	Seafarers	108	101-116
039	Managers in construction	123	113-133
043	Fishmongers, poultry dressers	132	102-167
046	Caterers	113	105-122
050	Fire service personnel	128	113-144
066	Fishing and related workers	123	105-143
082	Glass & ceramics furnace workers	145	118-176
089	Tobacco process operatives	135	100-178
112	Furnace operatives (metal)	132	115-151
116	Moulders and coremakers (metals)	114	101-128
117	Electroplaters	122	100-146
118	Annealers, hardeners, temperers (metals)	166	129-210
120	Other metal manufacturers	118	109-127
123	Machine tool setter operators	109	102-116
126	Metal polishers	119	100-142
127	Fettlers and dressers (metal)	131	106-159
128	Shot blasters	151	116-193
146	Metal plate workers, shipwrights, riveters	113	103-123
147	Steel erectors	126	115-137
148	Scaffolders, staggers, steeplejacks, riggers	127	116-139
158	Coach painters	114	103-127
167	Plasterers	119	109-129
168	Roofers and glaziers	124	113-136
<b>Women</b>			
013	Welfare workers	121	111-131
030	Other professional engineers	237	135-385
041	General & office managers	117	105-130
043	Fishmongers, poultry dressers	193	106-324
045	Publicans and bar staff	138	128-148
055	Petrol pump forecourt attendants	193	130-275
188	Fork lift & mechanical truck drivers	246	118-453

Source: Coggon *et al*. (2009) Occupational mortality in England and Wales, 1991-2000

## 2.2 EXPOSURES

### 2.2.1 Acrylonitrile

Acrylonitrile is extensively used in the manufacture of synthetic fibres, resins, plastics, elastomers and rubber for a variety of consumer goods, such as textiles, dinnerware, food containers, toys and others. Exposure only occurs in about 2,700 workers in GB mainly in the manufacture of industrial chemicals and other chemical products, rubber and plastic products. The working exposure limit (WEL)<sup>6</sup> is 2ppm

<sup>6</sup> The amount of a chemical in the workplace air that must not be exceeded.



(8-h TWA). Studies of acrylonitrile workers are limited in that they are very small, and exposure-response relationships could not be evaluated. IARC, therefore, considered the evidence to be limited and classified the chemical 2B (IARC, 1987).

Benn and Osborne (1998) studied the mortality experience of 2,763 men employed between 1950 and 1978 for at least one year at six factories involved in the polymerisation of acrylonitrile and the spinning of acrylic fibre. This was an update of the initial study by Werner and Carter (1981), the most recent analysis following them through 1991. There were 53 lung cancer deaths giving a standardised mortality ratio (SMR) of 1.03 (95%CI=0.77-1.35).

Collins and Acquavella (1998) reviewed 25 studies of workers and carried out a meta-analysis. The meta-relative risk (RR) for lung cancer was found to be 0.9 (95%CI=0.9-1.1). A previous similar analysis by Rothman (1994) revealed little evidence of carcinogenicity.

In a more recent review by Cole *et al.* (2008) the authors summarised the risk from four cohort studies: Du Pont study (Symons *et al.*, 2008), UK study (Benn and Osborne, 1998), NCI study (Blair *et al.*, 1998), and Dutch study (Swaen *et al.*, 2004a). The overall SMR was 0.98 (95%CI=0.88-1.09).

In a more complete review of 11 studies lung cancer risk ranged from 0.74 to 2.00 (Sponsiello-Wang *et al.*, 2006). Overall, the fixed-effects RR was 0.95 (95%CI=0.86-1.06), whereas the random-effects RR was 0.97 (95%CI=0.85-1.11).

Scelo *et al.* (2004) assessed the risk of lung cancer following exposure to acrylonitrile, as well as vinyl chloride and styrene. There were 2,861 cases and 3,118 matched controls from seven European countries that were recruited during 1998-2002. Only 39 cases and 20 controls were ever exposed to acrylonitrile, giving an OR of 2.20 (95%CI=1.11-4.36). There was no linear trend with duration of exposure. The linear trend between risk and cumulative exposure approached significance ( $p=0.06$ ); the risk in those with  $>1.6$  ppm-years cumulative exposure was 2.87.

## 2.2.2 Arsenic and arsenic compounds

Arsenic occurs in organic and inorganic forms. Inorganic arsenic has been known to be carcinogenic since the late 1960s and was classified Group 1 by IARC in 1980 (IARC, 1980) and again in 1987 (IARC, 1987). The main occupations with substantial historical exposure levels include hot copper smelting, manufacturing of arsenical pesticides and sheep-dip compounds, fur handlers and vineyard workers (Hayes, 1997, IARC, 1987) and some mining. The current HSE UK occupational exposure limit (WEL) is 2ppm (8-h time-weighted average (TWA)).

There is a substantial amount of literature linking inhalation exposure to inorganic arsenic and lung cancer. Most studies involved workers exposed primarily to arsenic trioxide dust in air at copper smelters (Axelson *et al.*, 1978, Enterline and Marsh, 1982a, Enterline *et al.*, 1987a, Enterline *et al.*, 1987b, Jarup *et al.*, 1989, Jarup and Pershagen, 1991, Lee-Feldstein, 1983) and mines (Liu and Chen, 1996, Qiao *et al.*, 1997, Taylor *et al.*, 1989, Xuan *et al.*, 1993). An increased incidence has also been observed at chemical plants where exposure was primarily to arsenate (Bulbulyan *et al.*, 1996, Mabuchi *et al.*, 1979, Ott *et al.*, 1974).

Enterline and Marsh (1982a) reported a significant increase in lung cancer mortality (SMR=1.89, 95%CI=1.55-2.30) over the years 1941–1976 in a cohort of 2,802 male workers employed for  $\geq 1$  year between 1940 and 1964 at the ASARCO smelter. When the cohort was separated into low and high arsenic exposure groups, lung cancer mortality was significantly increased in both groups in an exposure-response relationship (SMR=2.28 and 2.91 in the low and high groups, respectively). Enterline *et al.* (1987) re-analyzed these data using improved exposure estimates that incorporated historical measurements of arsenic in the ambient air and personal breathing zone of workers. Lung cancer mortality SMRs increased with increasing exposure to arsenic from 2.13 in the low, 3.12 in the medium, to 3.41 in the high arsenic exposure groups. Enterline *et al.* (1995) extended the mortality

follow-up from 1976 to 1986, and reported findings similar to the earlier study in a less thorough analysis.

Lung cancer mortality was significantly increased (SMR=2.85, 95%CI=2.54-3.19) between 1938 and 1977 in a cohort of 8,045 white male workers employed for at least 1 year between 1938 and 1956 at the Anaconda smelter (Lee-Feldstein, 1986). When workers were categorized according to cumulative arsenic exposure and date of hire, lung cancer mortality was significantly increased in all groups hired between 1925 and 1947. An analysis of a subset of the Anaconda cohort (n=1,800, including all 277 employees with heavy arsenic exposure and 20% of the others) that included information on smoking and other occupational exposures was performed by Welch *et al.* (1982). This analysis showed that lung cancer mortality increased with increasing time-weighted average arsenic exposure, with a small non-significant increase in the low group (SMR=1.38) exposed to 0.05mg/m<sup>3</sup> and significant increases in the medium (SMR=3.03), high (SMR=3.75), and very high (SMR=7.04) groups. Cohort members were more likely to be smokers than U.S. white males, but smoking did not differ among the arsenic exposure groups. Exposure-response analysis of smokers was similar to the analysis based on the full sub-cohort, while analysis of non-smokers also showed a similar pattern, but with lower SMRs. In a follow-up analysis of the same cohort, Lubin *et al.* (2000) re-weighted the exposure concentrations based on duration and time of exposure and re-evaluated the effects of exposure. Relative risks for lung cancer increased with increasing duration in each arsenic exposure area (light, medium, and heavy) after adjustment for duration in the other two exposure areas. SMRs were significantly elevated following exposure to 0.58 mg/m<sup>3</sup> (medium; SMR=3.01, 95%CI=2.0–4.6) or 11.3mg/m<sup>3</sup> (high; SMR=3.68, 95%CI=2.1–6.4) for 10 or more years, and following exposure to 0.29mg/m<sup>3</sup> (low; SMR=1.86, 95%CI=1.2–2.9) for 25 or more years.

Enterline *et al.* (1987) investigated the mortality experience from 1949 to 1980 of a cohort of 6,078 white males who had worked for 3 years or more between 1946 and 1976 at one of eight U.S. copper smelters. Lung cancer mortality was significantly increased at only one smelter (SMR=2.27), which had the highest average arsenic exposure concentration and also contributed the largest number of cohort members. A nested case-control study showed that arsenic exposure and cigarette smoking were significant risk factors for lung cancer in the smelter workers. Smoking was lower in the Utah smelter workers than in the other smelter workers, but still higher than in the referent Utah population, suggesting that the risk attributable to arsenic in this study population is somewhat lower than indicated by the SMR reported above.

Järup *et al.* (1989) reported significantly increased lung cancer mortality (SMR=3.72, 95%CI=3.04–4.50) based on 106 lung cancer deaths in a cohort of 3,916 male workers employed for ≥3 months between 1928 and 1967 at a Swedish smelter and followed for mortality through 1981. Workers were separated into low, medium, and high arsenic exposure groups. Lung cancer mortality was significantly increased in all three exposure groups, with a significant exposure-response relationship (SMR=2.01, 3.53, and 4.80, respectively). A nested case-control analysis of 102 lung cancer cases and 190 controls from the cohort showed that lung cancer risk increased with increasing arsenic exposure in non-smokers, light smokers, and heavy smokers (Jarup and Pershagen, 1991). The results demonstrated that arsenic is a risk factor for lung cancer in the smelter workers, but also suggested a greater-than-additive interaction between smoking and arsenic exposure. In this analysis, in contrast to the cohort study, lung cancer risk due to arsenic was increased only in the higher arsenic-exposure groups.

### **2.2.3 Asbestos**

Asbestos is an important occupational lung carcinogen but its use has been increasingly restricted, as its dangers became known. All forms of asbestos, serpentine (chrysotile) and amphiboles (crocidolite, amosite, tremolite, etc.) are carcinogenic to humans, although the potency of chrysotile might be lower than that of other types (IARC, 1987, IPCS, 1998).

Numerous studies have been published on asbestos-exposed occupational cohorts. Goodman *et al.* (1999) reviewed 69 studies that report cancer morbidity and/or mortality. The industries covered in this review included: gas mask manufacturers, insulation manufacturers, cement workers, vermiculite workers, miners and millers, railroad car construction workers, shipyard workers, asbestos textile workers, and others. For lung, without latency, 55 studies were considered for analysis and a meta-SMR of 1.48 (95%CI=1.44-1.52) was obtained, although there was significant heterogeneity. With latency of at least 10 years the meta-SMR was 1.63 (95%CI=1.58-1.69) but again with significant heterogeneity. To reduce the heterogeneity the analysis was stratified by occupation (Table 7). However, even within occupations there was significant heterogeneity.

**Table 7** Meta-analysis of lung cancer risk stratified by occupation (source: Goodman *et al.*, 1999)

	With Latency			Without Latency		
	No. of cohorts	Meta-SMR	95%CI	No. of cohorts	Meta-SMR	95%CI
All studies	37	1.63	1.58-1.69	55	1.48	1.44-1.52
Cement workers	9	1.70	1.56-1.85	9	1.58	1.44-1.73
Asbestos miners & millers	4	1.35	1.24-1.46	7	1.53	1.44-1.63
Asbestos products manufacturers	7	1.92	1.76-2.09	12	1.88	1.73-2.03
Shipyard workers	5	1.24	1.11-1.37	8	1.17	1.09-1.27
Textile workers	2	-	-	5	1.42	1.25-1.60
Friction materials workers	4	1.12	1.01-1.24	2	-	-
Railroad car maintenance & repair	4	0.90	0.79-1.01	5	0.93	0.83-1.04

The authors also analysed lung cancer risk by the percentage of mesothelioma deaths and observed a significant trend (Table 8).

**Table 8** Exposure-response relationship between lung cancer risk and proportionate mesothelioma mortality

Percentage of mesothelioma deaths	With Latency			Without Latency		
	No. of cohorts	Meta-SMR	95%CI	No. of cohorts	Meta-SMR	95%CI
0-0.6%	13	1.27	1.21-1.34	17	1.18	1.13-1.23
0.7-2.4%	10	1.38	1.26-1.51	13	1.53	1.42-1.64
Over 2.4%	11	2.85	2.71-2.99	15	2.49	2.38-2.61
Data not available	3	0.87	0.76-0.98	10	1.13	1.03-1.24

This evidence of an exposure-response relationship was supported by a statistically significant positive correlation coefficient.

In a review of the main lung carcinogens, Steenland *et al.* (1996) examined a subset of the papers in Goodman *et al.* (1999), plus some others, focussing on larger cohort studies, and those with some estimate of dose. They derived a combined SMR of 2.00 (95%CI=1.90-2.11).

Hodgson and Darnton (2000) carried out a review of 25 mortality reports on exposed cohorts which gave information on exposure levels from which a cohort average cumulative exposure could be estimated. They concluded that cohorts exposed only to crocidolite and amosite asbestos record similar exposure specific risk levels at around 5% excess lung cancer per fibre/ml-year. However, chrysotile-exposed cohorts show a less consistent picture at around 0.1%-0.5%. In studies that presented exposure-response relationship they concluded that lung cancer risk lies between a linear and square relationship, compared to the square of cumulative exposure for mesothelioma risk.

In 2006 Darnton *et al.* (2006) estimated the number of asbestos-related lung cancer deaths in GB from 1980 to 2000. The observed number of male lung cancer deaths at ages 16-74 during the period 1980-2000 (excluding 1981) by occupational group was modelled in terms of smoking and asbestos exposure using Poisson regression. They found that the effect of asbestos exposure in predicting lung cancer mortality was weak in comparison to smoking habits and occupation type. They estimated that the number of asbestos-related lung cancers was between 11,500 and 16,500 deaths during the time period. This is about 2-3% of all deaths. The authors concluded that asbestos-related lung cancers are likely to remain an important component of the total number of lung cancer deaths in the future as part of the legacy of past decade of asbestos exposure in occupational settings.

#### 2.2.4 Beryllium

Beryllium exposure occurs mainly in mining, refining and in the manufacture of ceramics, and electronic and aerospace equipment. A maximum exposure limit (MEL) of 2µg/m<sup>3</sup> (8-h TWA) was set in 2005, which was then converted to a workplace exposure level (WEL). IARC classify beryllium as a Group 1 carcinogen (IARC, 1993b).

A number of retrospective cohort mortality studies examining workers at beryllium processing facilities in Pennsylvania and Ohio have been conducted by Mancuso and Associates (Mancuso and el-Attar, 1969, Mancuso, 1970, Mancuso, 1979, Mancuso, 1980) and the National Institute of Occupational Safety and Health (NIOSH) (Bayliss *et al.*, 1971, Sanderson *et al.*, 2001, Wagoner *et al.*, 1980, Ward *et al.*, 1992); many of these studies examined one or two facilities and others looked at seven facilities. The early studies noted an increase in lung cancer mortality in the cohort of 3,685 Caucasian male workers employed at two beryllium facilities 1937 to 1948 with various follow-up periods. To determine whether these increased lung cancer deaths were due to beryllium exposure, or whether the excess risk could be attributed to personal characteristics of workers having unstable employment patterns, Mancuso (1980) conducted a fourth study of the cohort followed through 1976.

Employees in the viscose rayon industry served as a comparison group. A significant increase in lung cancer deaths was observed in the beryllium workers when compared to the entire cohort of rayon workers (SMR=1.40) or a sub-cohort of workers who did not transfer between departments during their employment in the viscose rayon industry (SMR=1.58). When the cohorts were divided into employment durations, significant increases in lung cancer deaths were observed in the workers employed for <12 months (SMRs=1.38 and 1.64 for total rayon cohort and those not transferring departments, respectively) and workers employed for >49 months (SMRs=2.22 and 1.72, respectively), but not in workers employed for 13–48 months. As with the other studies, the design of this study has been criticized. One limitation of this study is the lack of adjustment for the potential confounding effect of smoking. USEPA (1987) questioned whether there was an adjustment for potential age differences between the beryllium cohorts and noted that NIOSH re-analyzed the data from this study and found “serious problems with Mancuso’s analysis”.

NIOSH have investigated workers at the same facilities as Mancuso, as well as several other beryllium processing facilities. The original cohort consisted of over 10,000 male and female workers who had employment of at least a few days or longer in the beryllium industry (Bayliss *et al*, 1971). However, approximately 2,000 workers with inadequate records and all female workers (approximately 1,100) resulted in a study cohort of approximately 7,000 workers. The number of deaths overall among the beryllium workers was lower than expected (SMR=0.92), which was attributed to a healthy worker effect. An increased number of deaths due to lung cancer were observed in the beryllium workers (SMR=1.06), but the increase was not statistically significant. Limitations of this study include lack of analysis for potential effect of latency, elimination of over 2,000 workers due to incomplete records, and the combining of populations from several different plants into one cohort (MacMahon, 1994, USEPA, 1987).

A subsequent study sponsored by NIOSH and the Occupational Safety and Health Administration (OSHA) (Wagoner *et al*, 1980) investigated beryllium workers at one facility in Reading, Pennsylvania. The study cohort of 3,055 white males employed between 1942 and 1967 were followed through 1975, and mortality rates were compared to the U.S. white male population. A significant increase in lung cancer deaths (SMR=1.37, 95%CI=1.01-1.82) was observed in the beryllium workers. When deaths from lung cancer were categorised by latency period, significant increases in lung cancer deaths were found in workers with a latency period of at least 25 years (SMR=1.85, 95%CI=1.13-2.86); significant increases in lung cancer deaths were also observed in workers employed for <5 years and a latency period of at least 25 years (SMR=1.87, 95%CI=1.09-3.00). To assess the influence of lowering beryllium exposure concentrations, lung cancer deaths were categorised by date of initial employment. A significant increase in lung cancer deaths was observed in workers initially hired before 1950 (when strict beryllium controls were instituted) with a 25-year or higher latency period (SMR=1.86, 95%CI=1.14-2.87). An increase in lung cancer deaths was also observed in workers initially employed after 1950, across latency periods, but the difference was not statistically significant (SMR=1.52, 95%CI=0.61-3.14). The study authors note that using national mortality rates probably resulted in a 19% underestimation of cancer risk because Berks County, Pennsylvania (where 87% of the workers resided) has a lower age-adjusted lung cancer rate than the U.S. general population. However, USEPA (1987) notes that most of the beryllium workers residing in Berks County lived in the city of Reading, Pennsylvania with a lung cancer mortality rate 12% higher than the national rate. Thus, using the national rates may have resulted in an underestimation of expected deaths. The authors noted that the smoking habits of the beryllium workers would result in a 14% higher risk of lung cancer than the comparison population. The study authors also note that the frequency of cigarette smoking and the distribution of lung cancer cell type distribution support the conclusion that it is unlikely that “cigarette smoking per se could account for the increased risk of lung cancer among beryllium-exposed workers in this study.” However, a number of other limitations have been discussed (MacMahon, 1994, USEPA, 1987).

In a more recent study, Ward *et al.* (1992) examined mortality data for a cohort of 9,225 male workers employed at seven processing facilities in Ohio and Pennsylvania for at least 2 days in the period of 1940–1969; the workers were followed through 1988. Compared to the U.S. white male population,

mortality from all causes was slightly elevated among the beryllium workers (SMR=1.05; 95%CI=1.01–1.08). The elevated mortality rate was largely due to increases in respiratory cancer, non-malignant respiratory disease, and deaths from ischemic heart disease. The SMR for trachea, bronchi, and lung cancer was 1.26 (95%CI=1.12–1.42). Analysis of mortality data for each individual plant revealed that significant increases in lung cancer deaths were only found in two facilities: Lorain, Ohio (SMR=1.69) and Reading, Pennsylvania (SMR=1.24). For the total cohort, duration of employment was not associated with increased lung cancer deaths, but increased latency was associated with increased lung cancer deaths. In the total cohort, statistically significant increases in lung cancer deaths were observed in the >30 year latency category (SMR=1.46), workers employed for <1 year with a >30 year latency (SMR=1.52), and in the 25–30 year latency period for workers employed for <1 year. Among workers at the Lorain and Reading facilities, significant increases in cancer mortality were also observed in workers employed for <1 year with a 30-year latency (SMRs=1.68 and 1.42, respectively). The decade of hire also influenced lung cancer deaths; and this was independent of potential latency. The highest cancer mortality rates were observed among workers hired before 1950. Three of the seven beryllium-processing facilities were open in the 1940s; elevated cancer risks were observed at two of the facilities: Lorain (SMR=1.69; 95%CI=1.28–2.19) and Reading (SMR=1.26; 95%CI=1.02–1.56). The cancer risk was not significantly elevated in the plants operating during the 1950s or 1960s (the Lorain plant closed in 1948). The study authors also examined the influence of geographic variation in lung cancer mortality by comparing cancer mortality in the cohort with county lung cancer data. Ward *et al.* (1992) used smoking habit data available from a 1968 Public Health Survey (included approximately 16% of cohort and four facilities (including the Reading, Pennsylvania facility)) to account for this confounding variable. A smoking adjustment factor of 1.1323 was estimated using the available data on the beryllium cohort and smoking habit data for the U.S. population. The smoking-adjusted SMRs for the entire cohort, the Reading cohort, and the Lorain cohort are 1.12, 1.09, and 1.49, respectively.

In general, the early (prior to 1987) studies that associated beryllium exposure with lung cancer have one or more of the following limitations: inadequate control for confounding factors such as smoking; use of inappropriate comparison populations to estimate expected deaths from lung cancer; inclusion of employees in the beryllium industry who were not actually exposed to beryllium; use of inappropriate controls. The more recent studies by Ward *et al.* (1992), Steenland and Ward (1991), and Sanderson *et al.* (2001) have addressed many of these issues and provide strong data on the carcinogenic potential of beryllium in humans. NTP (1999, 2005) and IARC (1993b) have concluded that beryllium is a human carcinogen. IARC (1993b) noted that several aspects of the Ward *et al.* (1992) and Steenland and Ward (1991) studies support the conclusion that beryllium is a human carcinogen. In particular IARC noted (a) the consistency of lung cancer excess in most of the locations, (b) greater excess cancer risk in workers hired prior to 1950 when beryllium levels were much higher than in subsequent decades, and (c) the highest risk of lung cancer in individuals with acute beryllium disease and at the facility with the greatest proportion of acute beryllium disease.

Sanderson *et al.* (2001) undertook a nested case-control study of the NIOSH cohort. Each of the 142 cases were identified through 1992 and matched with five controls. Cases had shorter tenures and lower lifetime cumulative beryllium exposures than controls, but higher average and maximum exposures. However, after applying a 10 and 20 year lag, exposure metrics were higher for cases. Odds ratios (OR) in analyses lagged for 20 years were significantly elevated for those with higher exposure compared to the lowest exposure category. Significant positive trends were seen with the log of the exposure metrics, and smoking did not appear to confound these relationships. There were no striking differences between the proportion of cases and controls that had ever worked in selected departments or work areas, although cases had more frequently served as general labour and maintenance workers than the controls. These workers tended to encounter some of the highest beryllium exposures.

Levy *et al.* (2007) re-examined the nested case-control study of Sanderson *et al.* (2001), using non-transformed exposure metrics instead of log-transformed metrics. Regression analysis showed no

elevated ORs for any exposure variable, and challenges the conclusions of Sanderson *et al.* (2001) that there is a causal relationship between beryllium exposure and lung cancer.

### 2.2.5 Cadmium and cadmium compounds

Cadmium is principally used in electroplating, in compounds that serve as stabilisers for plastics, as pigments, in electrodes in batteries, and in alloys (IARC, 1993b, Schaller and Angerer, 1992). Exposures mainly occur via inhalation. MELs for cadmium and its compounds, except cadmium sulphide and cadmium pigments, are  $0.025\text{mg}/\text{m}^3$  (8-h TWA). Cadmium and its compounds were classified as a Group 1 carcinogen by IARC in 1993 (IARC, 1993b).

The results of studies investigating the effect of occupational exposure of cadmium are conflicting and carcinogenicity has not been unequivocally established in human studies. Overall, the results provided suggestive evidence of an increased risk of lung cancer following prolonged inhalation exposure to cadmium (ATSDR, 2008). However, cadmium and its compounds have been classified as a Group 1 carcinogen by IARC (1993b). Evidence comes from a study of US workers exposed at a recovery facility (Sorahan and Lancashire, 1997, Stayner *et al.*, 1992a, Stayner *et al.*, 1992b, Stayner *et al.*, 1993, Thun *et al.*, 1986, Thun *et al.*, 1985), nickel-cadmium battery facilities in England (Sorahan, 1987) and Sweden (Jarup *et al.*, 1998), and in a cohort of workers at processing facilities and/or smelters (Ades and Kazantzis, 1988, Kazantzis *et al.*, 1988, Kazantzis and Blanks, 1992).

Early studies of the recovery workers showed significant excesses of lung cancer. Stayner *et al.* (Stayner *et al.*, 1992a, Stayner *et al.*, 1992b) followed 576 workers employed for at least six months between 1940 and 1969, and followed them through 1984. The overall SMR, 1.49 (95%CI=0.96-2.22) was slightly greater than expected based on US national rates. Lung cancer mortality was significantly increased among non-Hispanic whites, among workers with the highest cumulative exposure ( $>2,291\text{mg}/\text{m}^3\text{-days}$ ), and among workers with the longest time since first exposure ( $>20\text{-years}$ ). The RR increased with cumulative exposure. When data were related to local rates the SMR increased to 3.87 (95%CI=1.55-7.97) in the highest exposure category compared to 2.80 when national rates were used. Lamm *et al.*, (Lamm *et al.*, 1992, Lamm *et al.*, 1994) conducted a nested case-control study that used period of hire as a surrogate for arsenic exposure. They reported no residual association of lung cancer with cadmium exposure. Cases were also more likely to have been smokers than controls. The authors therefore concluded that arsenic exposure and smoking were the major determinants of lung cancer risk, not cadmium exposure. Sorahan and Lancashire (1997), conducted further analyses, based on detailed job histories extracted from the time sheet records, to better resolve the potential confounding affects of arsenic. After adjustment for age attained, year of hire, and ethnicity there was a significant positive trend between cumulative exposure to cadmium and risk of mortality from lung cancer, being 3.88 (95%CI=1.04-14.46) at exposure  $\geq 2000\text{ mg}/\text{m}^3\text{-days}$ . A separate analysis examined the independent effects of exposure to cadmium (mainly cadmium oxide) received in the presence of high exposures to arsenic and exposures to cadmium received without such exposure to arsenic. A significant trend for a risk of lung cancer was found only for exposures to cadmium received in the presence of arsenic.

In the UK various studies of exposed workers have been carried out. A study of 347 copper/cadmium alloy workers investigated mortality between 1946 and 1992, and first employed in the period 1922-1978, for at least one year (Sorahan *et al.*, 1995). Their experience was compared to workers in areas close to alloy workers and in a brass/iron foundry. There were 825 deaths, 229 among alloy workers. However, there were only 18 lung cancer deaths giving an SMR of 1.01 (95%CI=0.60-1.59); the majority of these (15) occurred at one factory from which the comparison populations were drawn. At this factory risk was almost doubled (SMR=1.97) and only slightly greater than vicinity workers. Despite these findings risk was not related to cumulative exposure to cadmium.

In a study of nickel/cadmium battery workers, the mortality experience of 926 employees was investigated for the period 1947-2000 (Sorahan and Esmen, 2004). They were first employed between 1947 and 1975 for at least one year. There were 45 lung cancer deaths compared with 40.7 expected

(SMR=1.11, 95%CI=0.81-1.48). No trend was seen with year of hire, or period from commencing employment, and no exposure-response relationship was observed.

A study of similar workers in Sweden investigated 869 workers employed between 1940 and 1980, and followed them to 1992 (Jarup *et al.*, 1998). Sixteen lung cancer deaths were observed among male workers, giving an SMR of 1.76 (95%CI=1.01-2.87), and 15 incident cases observed resulting in an SIR of 1.73 (95%CI=0.97-2.85). The risk did not show any relationship with cumulative cadmium exposure, mean intensity or duration of exposure.

Among employees at a UK zinc-lead-cadmium smelter, mortality was examined among 4,393 workers (Ades and Kazantzis, 1988). Based on 182 lung cancer deaths the SMR was 1.25 (95%CI=1.07-1.44). An increasing linear trend in SMR was observed with increasing duration of employment. The SMR was shown to increase by a factor of 1.25 (95%CI=1.11-1.40) for every 10-years of employment, from an initial SMR of 0.88.

In 2003, Verougstraete *et al.* (2003) reviewed the epidemiologic data on exposures to cadmium and lung cancer, published since the IARC classification. They concluded that the cohort studies consistently found an increased lung cancer risk, despite different exposure conditions, in different cadmium industries, and in different countries. They noted some limitations in the studies, notably the inconsistencies of exposure-response relationships and potential confounding by arsenic.

## 2.2.6 Chlorinated toluenes and benzoyl chloride

*alpha*-Chlorinated toluenes ( $\alpha$ CT) and benzoyl chlorides (BC) are used in the manufacture of plasticizers that are used extensively in vinyl flooring and other flexible PVC uses such as food packaging. Other significant uses are in the dye industry and as intermediates in the production of pharmaceuticals, perfumes and flavour products (IARC 1998).

A mortality study of 953 workers potentially exposed to various chlorinated toluenes and BC was conducted in a factory in England (Sorahan *et al.*, 1983, Sorahan and Cathcart, 1989). Workers employed for at least six months between 1961 and 1970 were included. The initial study followed them to 1976, and workers were divided into those with low (n=720) and high (n=163) exposures. The risk among the exposed group was 2.81 (95%CI=0.91-6.56) compared to 1.28 (95%CI=0.55-2.53) among the low-exposed group. Sorahan and Cathcart (1989) extended the follow-up of the cohort to 1984, and conducted a nested case-control study. 26 cases of lung cancer were observed with an overall SMR of 1.79 (95%CI=1.17-2.63). The risk among the exposed group was still significantly increased at 3.31 (95%CI=1.59-6.09) and non-significantly raised in the other group at 1.39 (95%CI=0.80-2.27). The risk was the same in both periods of follow-up 1961-1976 and 1977-1984. Conditional logistic regression of the case-control data gave RRs of 1.4 (95%CI=0.4-4.2) for benzotrichloride, and 1.1 (95%CI=0.3-4.2) for other CTs per 10-years of exposed employment.

In a US study of 697 male employees of a chlorination plant, mortality was examined from 1943 through 1982 (Wong, 1988). For the entire cohort respiratory cancer was increased (SMR=2.46, 95%CI=1.01-5.15), and in white employees alone 2.65. Risk was elevated for three specific chemical exposure subgroups: benzotrichloride, SMR=2.6; benzyl chloride or benzoyl chloride, SMR=2.6.

## 2.2.7 Chloromethyl Methyl Ether and Bis(chloromethyl) Ether

Chloromethyl Methyl Ether (CMME) and Bis(chloromethyl) Ether (BCME) are primarily used as chemical intermediates and alkylating agents. BCME is used in the manufacture of plastics, ion-exchange resins, and polymers; it was formerly used in the surface treatment of vulcanised rubber to increase adhesion and in the manufacture of flame-retardant fabrics. CMME is used in the manufacture of dodecylbenzyl chloride, water repellents, ion-exchange resins, and polymers. A number of studies of occupationally-exposed workers indicate that inhalation of BCME or CMME containing BCME is associated with increased risk of lung cancer (Albert *et al.*, 1975, Collingwood *et*



*al*, 1987, Defonso and Kelton, 1976, Figueroa *et al*, 1973, Lemen *et al*, 1976, Maher and Defonso, 1987, Pasternack *et al*, 1977, Reznik *et al*, 1977, Roe, 1985, Sakabe, 1973, Thiess *et al*, 1973, Weiss and Boucot, 1975, Weiss, 1976, Weiss, 1982). Results of early studies are given in Table 9.

**Table 9** Lung cancer mortality in workers exposed to BCME and Technical Grade CMME

Reference	Exposed population	Duration of exposure	No. of observed/expected lung cancer deaths	Risk
Defonso & Kelton, 1976	669 chemical plant workers	Total	19/5.0	3.8
Weiss <i>et al.</i> , 1979	1446 chemical plant workers (465 exposed)	≤12 years	39/18.1	2.15
Pasternack <i>et al.</i> , 1977	721 chemical plant workers	≤19 years	23/4.5	5.1
Collingwood <i>et al.</i> , 1987	762 chemical plant workers	≤31 years	32/7.5	4.3
Lemen <i>et al.</i> , 1976	136 anion-exchange plant workers	≥5 years	5/0.54	9.24

In an update of a cohort of 125 chemical workers established in 1963, 93 were exposed to CMEs (Weiss and Nash, 1997). There were 25 lung cancer deaths (4.81 expected), giving an SMR of 5.20 (95%CI=3.36-7.70). Of these, 22 were exposed to CMME (SMR=6.65, 95%CI=4.17-10.04), and a significant exposure-response was observed (Table 10).

**Table 10** SMRs and Attributable Numbers for Lung Cancer Deaths by CME Exposure Group, 1963 to 1992 (source: Weiss & Nash, 1997)

Exposure index	SMR	95%CI
>0-<10	1.38	0.17-4.98
10-<20	7.49	3.23-14.75
>20	15.21	7.87-26.6

In a cohort of UK CMME manufacture workers at two factories, a total of 1,767 individuals were traced and vital status followed up to 1980 (McCallum *et al*, 1983). Twenty lung cancer deaths were observed, 11 among exposed and 9 among unexposed workers. At one factory the RR of lung cancer for the exposed group was 10.97. There was also a trend of increased with increased risk of exposure.

### 2.2.8 Chromium (hexavalent) compounds

Chromium adds rust and acid resistance properties as well as hardness to alloys. Stainless steel manufacture accounts for a significant proportion of all use of chromium. Worker exposures occur in its production, as well as the production of other alloys, chrome-containing pigments, chrome-plating and welding (of stainless steel) (IARC, 1990). The current MEL is 0.05  $\mu\text{g}/\text{m}^3$  (8-h TWA). Studies carried out globally of workers in the chromate production industry have consistently shown excess risks for lung cancer (IARC, 1990).

Occupational exposure to hexavalent chromium (CrVI) compounds in a number of industries has been associated with an increased risk of lung cancer. Among the industries studied are chromate production, chromate pigment production and use, and chrome plating. Other industries of CrVI exposed workers including alloy production, and leather tanning have been inconclusive or consistently negative.

There have been a large number of studies of production workers (Alderson *et al*, 1981, Bidstrup, 1951, Bidstrup and Case, 1956, Davies *et al*, 1991, Enterline, 1974, Hayes *et al*, 1979, Mancuso and Hueper, 1951, Mancuso, 1975, Mancuso, 1997, Pastides *et al*, 1991, Pastides *et al*, 1994, Rosenman and Stanbury, 1996). Three recently published studies have been undertaken. Gibb *et al*. (2000) investigated a US cohort of 2,357 workers first employed between 1950 and 1974 and followed to 1992. There were a total of 855 deaths, 235 from cancer. A total of 122 lung cancer deaths were observed (SMR=1.80, 95%CI=1.49-2.14). The risk was similar among whites (SMR=1.86, 95%CI=1.45-2.34) and blacks (SMR=1.88, 95%CI=1.38-2.51). Lung cancer cases had a significant greater mean and median CrVI exposure (0.29mg/m<sup>3</sup>-years) compared to non-cases (0.125 mg/m<sup>3</sup>-years). A significant exposure-response relationship was observed with cumulative exposure, with risk above an exposure of 0.09 mg/m<sup>3</sup>-years being significant (see Table 11). There were slight differences in the relationship between whites and blacks. Regression analysis indicated the excess lung cancer risk was not confounded by smoking status.

**Table 11** Exposure-response relationship between hexavalent chromium exposure and lung cancer risk among production workers (source: Gibbs *et al.*, 2000)

Exposure (mg/m <sup>3</sup> -years)	Observed/Expected	SMR (95%CI)
0-0.00148	26/27.138	0.96 (0.63-1.40)
0.00150-0.0089	28/19.781	1.42 (0.94-2.05)
0.009-0.0769	30/19.122	1.57 (1.06-2.24)
0.077-5.25	38/16.631	2.28 (1.62-3.14)

Luippold *et al.* (2003) assessed mortality in 1997 among 493 former workers of a US chromate production plant employed for at least one year between 1940 and 1972. There were 203 deaths, 90 from cancer including 51 from lung cancer. The latter resulted in an SMR of 2.41 (95%CI=1.80-3.17) when compared to local rates, and 2.68 (95%CI=2.00-3.52) when compared to national rates. The risk was significantly greater in those hired before 1960 (no excess in those hired after). Risk also increased significantly with duration of employment but not with time since first exposure. A highly significant exposure-response relationship was observed with cumulative exposure, the risk at exposures greater than 2.70 mg/m<sup>3</sup>-years being 4.63 (95%CI=2.83-7.16).

In a German study, mortality experience of 901 workers at two plants in 1998 was examined (Birk *et al.*, 2006). The workers had started work in 1958. There were 130 deaths, 47 from cancer including 22 from lung cancer, SMR = 1.48 (95%CI=0.93-2.25). No consistent trends were observed with duration of exposure or time since first exposure. A statistically significant two-fold increase in mortality was observed among employees with a cumulative concentration of CrVI in their urine of 200 or more µg/L-years (SMR=2.09, 95%CI=1.08-3.65). Below this exposure there was no excess risk, and similar risks were observed when the analysis was lagged 10 and 20 years.

Crump *et al.* (2003) evaluated the exposure-response relationship between CrVI exposure and lung cancer in the Luippold cohort. Airborne exposure data were collected over the history of the plant and exposure estimates were reconstructed using a job-exposure-matrix (JEM) approach that combined job titles with area monitoring data. Regression analysis showed that the lifetime additional risk of lung cancer mortality associated with 45 years of occupational exposure to 1µg/m<sup>3</sup> CrVI was 0.002 (90%CI=0.001-0.003) for both relative risk and additive risk models. They thus concluded that CrVI is a weak carcinogen.

Studies of workers engaged in the production of chromate pigments have also consistently shown an association with increased risk of lung cancer. A study of the causes of death among 1,296 white and 650 non-white males who had worked at some time between 1940 to 1969 at a plant in New Jersey manufacturing lead and zinc chromate pigments showed an SMR for lung cancer of 1.60 (95%CI=1.06-2.38) for white males compared with U.S. rates (Sheffet *et al.*, 1982). The cohort included workers with exposures classified as high (continuous exposure, >2mg total chromium/m<sup>3</sup>); moderate (occasional exposure, 0.5–2mg/m<sup>3</sup>); and low (infrequent exposure, <0.1mg/m<sup>3</sup>). The SMR increased to 1.90 (95%CI=0.99-3.18) for white males employed for at least 2 years and who had "moderate" exposure to chromates (0.5–2mg/m<sup>3</sup>). Air monitoring at the plant in the later years (not specified) indicated exposure concentrations from <0.1 to >2mg/m<sup>3</sup> and a ratio of lead to zinc chromate of 9:1. Smoking histories were not available for all workers. A follow-up of this study to 1982 gave 453 deaths, 41 of which were due to lung cancer, resulting in a non-significant SMR of 1.16 (95%CI=0.83-1.58). When analyzed by duration of employment, none of the SMRs were significant, but there was a significant trend for increased risk with increasing duration of employment (p=0.04). When time since initial employment was considered in the analysis, a significantly increased risk of lung cancer was found in those employed for >10 years with >30 years since initial employment (SMR=1.90, 95%CI=1.11-2.95). Of the 41 lung cancer deaths, 24 occurred in those whose jobs involved exposure to chromate dusts (i.e., with exposures of 0.5 to >2mg/m<sup>3</sup>). Results of

the analysis of SMRs and trends for these 24 lung cancer deaths by duration of employment and time since initial employment along with duration of employment were similar to those obtained with the 41 lung cancer deaths (Hayes *et al*, 1989).

Another epidemiological study of workers at three chromate pigment production plants in the US investigated the causes of death in 574 male workers with known exposure to lead chromate and who had been employed for at least 6 months from the mid-1920s to December 31, 1979 (EEH, 1976, EEH, 1983). At Plant 1, where lead chromate was the only chromate produced, there were 21 deaths among 246 workers, four of which were due to respiratory cancer (SMR=1.64, 95%CI=0.45-4.27). At least two of the deaths from lung cancer occurred in workers who smoked. At Plant 2, zinc chromate, strontium chromate, and barium chromate had also been produced at various times during the facility's operation. There were 11 deaths among 164 workers, 2 of which were due to respiratory cancer (one expected). Both of the workers with respiratory cancer had been smokers. At Plant 3, lead chromate was one of many products, and zinc chromate had also been produced. There were 53 deaths among 164 workers, 9 of which were due to cancer of the bronchus, trachea, and lung (SMR=2.31, 95%CI=1.06-4.38). At least five of the lung cancer patients had been moderate to heavy smokers. Because of the non-significant rate of respiratory cancer at Plant 1 and the co-exposure to other chromates at Plants 2 and 3, no conclusions regarding the risk of lung cancer in lead chromate-exposed workers could be drawn from this study. Combining the results for lung cancer from Plants 2 and 3 gave an SMR of 2.28 (95%CI=1.14-4.10), suggesting that exposure to zinc chromate (and other chromates) is associated with an increased risk of lung cancer.

Three chromate pigment manufacturing plants in the United Kingdom have been studied (Davies, 1979, Davies and Kirsch, 1984). At Factory A, both lead and zinc chromate were produced from 1932 to 1964, after which lead chromate production ceased. The main cohort consisted of 411 men first employed between 1932 and 1967. For workers exposed to "high" and "medium" levels of chromates before 1955, when industrial hygiene improvements had been introduced, 22 cases of lung cancer death were observed (SMR=2.32, 95%CI=1.45-3.51). No excess of lung cancer was found in the group exposed after 1955 or in workers exposed to "low" levels. At Factory B, both lead and zinc chromate were produced until 1976, and strontium chromate from 1950 to 1968. The main cohort consisted of 138 men first employed between 1948 and 1967. For lung cancer deaths in workers exposed to "high" and "medium" levels of chromates before 1961, when industrial hygiene improvements were introduced, the SMR was 3.73 (95%CI=1.37-8.11), based on six deaths. For workers exposed to "high" and "medium" levels from 1961 to 1967, the SMR was 5.62 (95%CI=1.82-13.1). At Factory C, where only lead chromate had been produced, no excess death from lung cancer was found (Davies, 1979), and meaningful analysis by subgroups was precluded (Davies and Kirsch, 1984). The results suggested that exposure to both zinc chromate and lead chromate posed more of a risk for lung cancer than exposure to lead chromate alone. Although information regarding smoking habits of the workers was not available, smoking was not permitted during work, suggesting that the workers smoked no more, or perhaps less, than other members of their socioeconomic status.

In other studies of chromate pigment producing workers significant excesses of lung cancer was observed in Norway (Langard and Norseth, 1975, Langard and Vigander, 1983), Germany (Frentzel-Beyme, 1983), and France (Haguenoer *et al*, 1981).

Studies on the risk of cancer in chrome platers have produced both positive and negative results, but they generally support the conclusion that CrVI is carcinogenic. In an analysis of the cause of death among 172 white male and 49 white female employees engaged for at least 10 years in die-casting and electroplating at an automobile hardware manufacturing plant in the US, statistically significant SMRs were found for respiratory system cancers in men (SMR=1.95, 95%CI=1.32-2.79; 30 cases) and women (SMR=3.57, 95%CI=1.71-6.57), and for lung cancer specifically in men (SMR=1.91, 95%CI=1.27-2.76) and women (SMR=3.70, 95%CI=1.78-6.81) (Silverstein *et al*, 1981). The SMR for lung cancer was significant in men with >15 years service, but not for men with <15 years service.

A study of 276 male electroplaters who were exposed to chromic acid and had worked for at least 3 months within 10 years prior to 1959 at two U.S. military aircraft maintenance bases and followed through 1977 found no excess of cancer compared with national rates (Dalager *et al*, 1980).

Although a significant increase in the incidence of death from all malignant diseases was found, no significant differences were found for lung cancer among 1,238 past and current chrome platers in 54 facilities in Yorkshire, United Kingdom, compared with a control group of 1,099 workers in other departments (Royle, 1975a, Royle, 1975b). However, another mortality study of a cohort of 2,689 (1,288 men, 1,401 women) chrome platers employed for at least 6 months in a different plant in the United Kingdom between 1946 and 1975 found an excess risk for cancer of the lungs and bronchus (SMR=1.58, 95%CI=1.21-2.02). No excesses were found for women alone. Most of the excesses in men were attributed to working in the chrome bath works, where exposures were mainly to CrVI as chromic acid. The correlation with duration of chrome bath work was positive only for cancers of the lung and bronchus. While data on smoking habits were not available, the investigators did not believe that duration of chrome employment would correlate with smoking habits (Sorahan *et al*, 1987). In a follow-up to this study, Sorahan *et al.* (1998) examined mortality rates in this cohort of chrome workers for the period of 1946–1995. The job history data were further refined and workers with no exposure to chromium were removed from the analyses, resulting in a cohort of 1,762 chrome workers (812 men and 950 women). Significant excess risks of lung cancer were observed among males and females working in the chrome bath area for <1 year (SMR=1.72, 95%CI=1.12–2.77) or greater than 5 years (SMR=3.20, 95%CI=1.28–6.58), females working in the chrome bath area for <1 year (SMR=2.45, 95%CI=1.18–4.51), males starting chrome work in the period of 1951–1955 (SMR=2.10, 95%CI=1.32–3.17), and in male chrome workers 10–19 years after first chrome work (SMR=2.03, 95%CI=1.21–3.21). A significant ( $p<0.01$ ) positive trend for lung cancer mortality and duration of exposure was found for the male chrome bath workers, but not for the female workers. Lung cancer mortality risks were also examined using an internal standard approach, in which mortality in chrome workers was compared to mortality in workers without chromium exposure. After adjusting for sex, age, calendar period, year of starting chrome work, period from first chrome work, and employment status, a significant positive trend ( $p<0.05$ ) between duration of chrome bath work and lung cancer mortality risk was found.

Sorahan and Harrington (2000) investigated mortality in a cohort of 1,087 chrome platers between 1972 and 1997, who were employed for three months or more during this period. Among the exposed workers there were 109 deaths, whereas in a similar unexposed group of workers there were 85. Among men there were 60 lung cancer deaths among platers compared to 47 among the comparison group. This resulted in SMRs of 1.85 (95%CI=1.41-2.38) and 1.27 (95%CI=0.94-1.69), respectively, and an SMR ratio of 1.45 (95%CI=0.97-2.17). There was no trend of risk increasing with duration of exposure among platers, and the risk was similar among current and former workers. The RR was slightly reduced after adjustment for smoking. In a matched analysis a RR of 1.92 (95%CI=1.14-3.28) was obtained.

Cole and Rodu (2005) reviewed 84 papers of 49 epidemiologic studies published since 1950, and undertook a range of meta-analyses relating CrVI exposure to mortality. A total of 47 studies examined lung cancer with a total of 2,454 deaths, whereas 1,741 were expected. This resulted in an overall SMR of 1.41 (95%CI=1.35-1.47). In 26 studies that controlled for smoking the SMR was reduced to 1.18 (95%CI=1.12-1.25) based on 1,325 cases whereas 1,118 were expected. Analysis of studies that did not control for smoking indicated that about 75% of the excess risk is probably due to smoking. The authors stated that these findings suggested the accepted causal relationship between CrVI exposure and lung cancer is valid but somewhat weaker than generally has been considered. It has been postulated that the relationship is weak because of the lung's capacity to reduce CrVI to the non-carcinogenic CrIII (de Flora, 2000), and that only very heavy exposure to CrVI could overwhelm the lungs reducing capacity and produce cancer.

### 2.2.9 Cobalt

In a recent re-evaluation by IARC, cobalt metal with tungsten carbide was classified in Group 2A, although cobalt metal without tungsten carbide, cobalt sulphate and other soluble cobalt II salts remain in Group 2B (Rousseau *et al*, 2005). Cobalt metal is used to make corrosion- and wear-resistant alloys used in aircraft engines, magnets and high-strength steels and other alloys. It is also added to metallic carbides, especially tungsten carbide, to prepare hard metals for metal-working tools. Cobalt is also used to manufacture cobalt-diamond grinding tools, cobalt discs and other cutting and grinding tools made from cobalt metal. Other uses include as catalysts and in batteries, dyes and pigments. Occupational exposure to cobalt occurs predominantly during refining of cobalt, in the production of alloys, and in the manufacture and maintenance of hard-metal tools and the use of diamond-cobalt tools (IARC, 2006b). CAREX estimates about 36,000 workers in GB were exposed to cobalt and its compounds in the early 1990s, distributed widely across manufacturing industry including fabricated metal products (accounting for 18%) and furniture and fixtures (12%).

Moulin *et al.* (1998) investigated vital status in a cohort of 7,459 workers (5,777 men, 1,682 women) in the French hard metals industry. The cohort was followed up between 1968 and 1991, and during that time there were 63 lung cancer deaths. This resulted in an overall SMR of 1.30 (95%CI=1.00-1.66). In a nested case-control of 61 cases and 180 matched controls, a significant lung cancer risk was observed among workers simultaneously exposed to cobalt and tungsten carbide (OR=1.93, 95%CI=1.03-3.62) and when adjusted for other cobalt exposure (OR=2.21, 95%CI=0.99-4.90). The OR increased with cumulative exposure (first quartile OR=1.00, second quartile OR=2.64, third quartile OR=2.59, fourth quartile OR=4.13) and, to a lesser degree, with duration of exposure. Adjustments for smoking and other known lung carcinogens did not change the results.

In a follow-up study of 2,860 (2,216 men, 644 women) workers at the largest production site, with an additional year's follow-up, 46 lung cancer deaths were found (Wild *et al*, 2000). In this smaller cohort the overall SMR for lung cancer was 1.70 (95%CI=1.24-2.26) for workers exposed to hard metals. For workers exposed to cobalt, except in hard metals, the SMR was 1.95 (95%CI=1.09-3.22)

In a detailed study of 4897 workers at a French factory producing stainless and alloyed steel employed between 1968 and 1991 there were 54 lung cancer deaths (all male) resulting in an SMR of 1.20 (95%CI=0.90-1.57) (Moulin *et al*, 2000). In a subsequent nested case-control study of these cases significantly more were involved in ring manufacture. Among the cases, 17 were exposed to cobalt compared to 67 controls, which resulted in a low OR of 0.64 (95%CI=0.33-1.25), which was reduced to 0.57 (95%CI=0.16-1.14) after adjustment for smoking. There was also no trend with any exposure metrics.

Moulin *et al.* (1993b) also investigated mortality at a French electro-chemical plant that produced cobalt. A total of 1,148 male workers employed 1950-1980, were followed-up to 1988. A total of eight lung cancer deaths were observed. Three cases were exclusively employed in cobalt production giving an SMR of 1.16 (95%CI=0.24-3.46), whereas four were ever employed in its production (SMR= 1.8, 95%CI=0.32-3.03). The results, however, were not adjusted for smoking.

### 2.2.10 Crystalline Silica

CAREX estimates about 590,000 GB workers were exposed to crystalline silica between 1990 and 1993. The majority of these were in the construction industry (76.3%); followed by the manufacture of other non-metallic mineral products (4.1%) and of pottery, china and earthenware (3.7%), plus machinery except electrical (2.8%) and other mining (2.8%). The main industries in which exposure occurs are masonry and stonework, concrete and gypsum, pottery, foundries, diatomaceous earth mining and brick making. Exposure is also a concern among miners where the ore has high silica content. The risk of lung cancer has been shown to be consistently increased in silicotics (IARC, 1997b, Steenland and Stayner, 1997). For the IARC (1997b) evaluation nine studies were considered because they provided the least confounded examinations of an association between silica exposure

and cancer risk (Burgess *et al*, 1997, Checkoway *et al*, 1993, Checkoway *et al*, 1996, Chen *et al*, 1992, Cherry *et al*, 1997, Costello and Graham, 1988, Costello *et al*, 1995, Dong *et al*, 1995, Guenel *et al*, 1989, McDonald *et al*, 1997, McLaughlin *et al*, 1992, Merlo *et al*, 1991, Winter *et al*, 1990). Not all these studies demonstrated an excess cancer risk, but in view of the relatively large number of studies that have been undertaken and, given the wide range of populations and exposure circumstances studied, some non-uniformity of results would be expected. In making their overall evaluation, the Working Group noted that carcinogenicity in humans was not detected in all industrial circumstances studied, and may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs.

Since the IARC (1997b) monograph many more papers have been published of lung cancer risk in industries with and without confounding exposures that have added to the weight of evidence. In addition a number of reviews, meta-analyses and a pooled analysis have been undertaken reaffirming this classification. IARC have recently carried out a review of Group 1 carcinogens and again reaffirmed the carcinogenicity of crystalline silica as Group 1 (Straif *et al*, 2009).

Since 1997 there have been seven meta-analyses published. Tsuda *et al*. (1997) examined the relationship between silicosis/pneumoconiosis and lung cancer mortality in 32 eligible studies published between 1980 and 1994. In all of these studies an excess of lung cancer mortality was observed. Using a random effects model the combined RR (CRR) was 2.76 (95%CI=2.41-3.16), with a CRR for cohort studies (n=25) of 2.78 (95%CI=2.41-3.22) and a CRR for case-control studies (n=5) of 2.79 (95%CI=2.00-3.89); these estimates are slightly higher than those of Smith *et al*. (1995). Although a majority of the studies did not adjust for smoking, those that did observed no difference between crude and adjusted estimates.

Steenland and Stayner (1997) carried out a review of 19 cohort and case-control studies of silicotics published between 1966 and 1995. They omitted studies in mines and foundries, which, they stated, might involve confounding exposures, autopsy and proportional mortality studies. The summary RR for these studies was 2.3 (95%CI=2.2-2.6). This compared with the summary RR of 2.2 previously found by Smith *et al*. (1995) on a similar group of studies. In a further analysis of 16 larger studies of silica-exposed workers with documented exposure, and without known confounding exposures to lung carcinogens (e.g. arsenic and radon) a combined RR of 1.3 (95%CI=1.2-1.4) was obtained.

Finkelstein (2000) reviewed eight studies that provided quantitative information about silica exposure and the risk of silicosis and lung cancer, published between 1989 and 1999. All eight studies showed that the risk of silicosis was greater at 4mg/m<sup>3</sup>-years cumulative exposure than at 2mg/m<sup>3</sup>-years. Finkelstein showed that lung cancer RR increased with cumulative exposure (lagged 15-20 years), each RR being significant, up to 1.74 (95%CI=1.65-1.82) in the highest exposure group. The risk of lung cancer increased by about 16% per mg/m<sup>3</sup>-year, and the risk following a lifetime exposure at 0.1 mg/m<sup>3</sup> was increased by 30% or more. At the same level of exposure the risk of silicosis (ILO category 1/1 or more) was estimated to be at least 5-10%, and 30-years exposure at 0.1mg/m<sup>3</sup> was estimated to give a lifetime silicosis risk of about 25%; exposure at 0.05mg/m<sup>3</sup> was estimated to give a risk of under 5%.

A similar analysis of studies published between 1966 and 2004 reviewed 31 studies (27 cohort and 4 case-control) that looked at the association between silicosis and lung cancer (Lacasse *et al*, 2005). Without any adjustment for smoking, the meta-analysis of the cohort studies gave a CRR = 2.45 (95%CI=1.63-3.66), with significant heterogeneity between studies that could not be explained by removing specific cohorts. In cohorts for which mortality were adjusted for smoking the CRR was 1.60 (95%CI=1.33-1.93). When the results of the cohorts were restricted to never-smokers, the pooled SMR was 1.52 (95%CI=1.02-2.26). When studies of underground miners were excluded, thereby reducing the possibility of confounding by radon exposure, the CRR was 2.47 (95%CI=1.76-3.48). In a further analysis, studies of compensation registries were excluded and a CRR of 2.67 was obtained (95%CI=1.68-4.25). Lung cancer risk was analysed by radiological severity of silicosis, as a surrogate for 'dose'. For simple silicosis, the risk of lung cancer increased by 1.33 (95%CI=1.16-1.53) for every

increment in category. For complicated silicosis the risk increased by 1.67 (95%CI=1.52-1.83). For case-control studies the summary risk was 1.70 (95%CI=1.15-2.53).

A recent meta-analysis estimated the RRs of lung cancer due to silica and silicosis from 30 studies published between 1966 and 2001 (Kurihara and Wada, 2004). Studies were removed if they did not exclude the effects of asbestos and radioactive materials including radon. Using a random-effects model the CRR of lung cancer RRs was 1.32 (95%CI=1.23–1.41) in subjects exposed to silica, 2.37 (95%CI=1.98–2.84) in silicotics only (based on 16 studies), whereas no increase in risk emerged in non-silicotics with exposure to silica (pooled RR=0.96, 95%CI=0.81–1.15, based on eight studies). The authors commented that some of the studies included in the analysis of silica did not exclude silicosis, and therefore the pooled estimate due to silica might be smaller than 1.32. Lung cancer risk in relation to radiographic category of silicosis showed no significant trend, although the trend was slightly downward. Lung cancer risk from silicosis in smokers was estimated to be 4.47 (95%CI=3.17-6.30) compared to 2.24 (95%CI=1.46-3.43) in non-smoking silicotics.

An analysis by Pelucchi *et al.* (2006) included 28 cohort, 15 case-control and two PMR studies published between 1996 and July 2005. Using a random-effects model the pooled RR from all cohort studies was 1.34 (95%CI=1.25-1.45). However, when studies were split into those that considered silicotics only and those where silicosis status was undefined, markedly different pooled estimates were obtained. In the one study of non-silicotics the pooled RR was 1.19 (95%CI=0.87-1.57). For case-control studies a similar pattern of estimates was observed. For the PMR studies, where silicosis was unknown, the CRR was 1.24 (95%CI=1.05-1.47). In both case-control studies and PMR studies, therefore, if some of the studies with undefined silicosis status had included silicotics then the risk estimate would be expected to be lower. There were variable results by different occupational settings, with more heterogeneity of occupational exposures (table 12). Pooled RRs among ceramics, diatomaceous earth (DE) and refractory brick workers, and for studies with miscellaneous exposure, were similar for both cohort and case-control studies. However, the pooled RR for miners was slightly higher in case-control studies than in cohort studies.

**Table 12** Pooled RRs according occupational setting, undefined silicosis status (source: Pelucchi *et al.* (2006))

Occupational group	Cohort studies	Case-control studies
Miners (underground & surface)	1.17 (1.03-1.32)	1.47 (1.19-1.82)
Sand workers	1.29 (1.03-1.61)	
Ceramics, diatomaceous earth & refractory brick workers	1.40 (1.11-1.75)	1.26 (0.99-1.62)
Miscellaneous exposure	1.17 (1.12-1.22)	1.24 (1.02-1.52)

In addition to the meta-analyses, Steenland *et al.* (2001) have carried out a pooled analysis of 10 silica-exposed cohorts published between 1988 and 2000 that had quantitative exposure data, or for which such data could potentially be developed. The pooled cohort included 65,980 workers (44,160 miners, 21,820 non-miners), and 1,072 lung cancer deaths (663 miners, 409 non-miners). The combined SMR for all the studies was 1.2 (95%CI=1.1-1.3). The authors showed that the log of cumulative exposure with a 15-year lag, was a strong predictor of lung cancer ( $p=0.0001$ ), with a strong consistency across studies. Internal analysis indicated that showed a dose-response relationship across quintiles of cumulative exposure, the RRs for lung cancer being 1.0 (reference), 1.0 (95%CI=0.85–1.3), 1.3 (95%CI=1.1–1.7), 1.5 (95%CI=1.2–1.9) and 1.6 (95%CI=1.3–2.1), although there was considerable heterogeneity across the studies. The authors compared the exposure-response relationship between miners and non-miners, and showed there were slight differences in lung cancer risk at the lower end of exposures (table 13).



**Table 13** Lung cancer risk by cumulative RCS exposure for miners and non-miners (source: Steenland *et al.* (2001))

Cumulative exposure (mg/m <sup>3</sup> -years)	All cohorts	Miners	Non-miners
<0.4	1.0	1.0	1.0
0.4-2.0	1.0 (0.85-1.3)	0.9 (0.66-1.2)	1.2 (0.92-1.6)
2.0-5.4	1.3 (1.1-1.7)	0.81 (0.59-1.1)	2.1 (1.6-2.8)
5.4-12.8	1.5 (1.2-1.9)	1.2 (0.89-1.6)	1.7 (1.2-2.4)
12.8+ (median 28.0)	1.6 (1.3-2.1)	1.4 (1.0-1.9)	1.5 (0.97-2.4)

The study showed duration of exposure did not fit the data well, indicating the importance of including exposure intensity into the exposure metric. However, an increasing trend with cumulative exposure was found; the excess lifetime risk, through age 75, for a worker exposed from age 20 to 65 at 0.1mg/m<sup>3</sup> RCS was 1.1-1.7% above background risks of 3-6%.

### 2.2.11 Diesel Engine Exhaust

Diesel engine exhaust (DEE) is a complex mixture of substances characterised by PAHs surrounding an elemental carbon core. The gas phase includes carbon monoxide and nitrogen oxides, but it is the particulate phase of the exhaust that appears to be implicated as the lung carcinogen. Approximately half a million workers in GB were exposed to DEE in the early 1990s. The majority of these were involved in land transport (33.5%), construction (22.5%) and personal and household services (14.6%). IARC have evaluated DEE, stating there is limited evidence for its carcinogenicity (Group 2A).

Death certificates of all men who died aged under 40 years between 1975 and 1979 with an underlying cause of death of cancer of the lung were obtained by Coggon *et al.* (1984). Two controls per case who did not die of lung cancer, matched on age, year of death and local authority area of residence, were also selected. The occupations recorded on the death certificates were coded to occupational units in the Office of Population Censuses and Surveys Classification of Occupation 1970. These were then grouped according to their likelihood of high, medium and low exposure to 9 carcinogenic substances including DEE. Asbestos related occupations showed highly significant associations with lung cancer. There was a statistically significant increased risk associated with DEE for all occupations (RR=1.3, 95%CI=1.0-1.6) and a non-significantly raised risk for those with high exposure (RR=1.1, 95%CI=0.7-1.8).

Two reviews have been undertaken recently evaluating the association between DEE exposure and lung cancer risk (Bhatia *et al.*, 1998, Lipsett and Campleman, 1999). Bhatia *et al.* (1998) evaluated 29 DEE epidemiological studies and selected 23 for inclusion in a meta-analysis. (studies of miners were excluded due to the potential for exposure to multiple airborne substances in the industry). Ten of the studies controlled for smoking. For all 29 studies the lung cancer RR was 1.33 (95%CI=1.27-1.40). There was no difference between cohort and case-control studies. In studies that adjusted for smoking the pooled RR was 1.35 (95%CI=1.22-1.49). However, there was significant heterogeneity between studies which was reduced when the analysis was stratified by occupational setting in which DEE exposure occurred.

Lipsett and Campleman (1999) included 30 studies (out of 47), that contained risk estimates, in their analysis that met their inclusion criteria. Occupations varied and included truck drivers, road maintenance, mechanics, railroad workers, heavy equipment operators, bus drivers and garage workers, dock workers, and other exposed worker groups. Individual study RRs ranged from 0.6 to 3.32. The overall pooled RR was 1.33 (95%CI=1.21-1.46) with little difference between cohort (1.29, 95%CI=1.14-1.47) and case-control (1.44, 95%CI=1.33-1.56) studies. In studies that adjusted for smoking the pooled RR was 1.43 (95%CI=1.31-1.57), or 1.47 (95%CI=1.29-1.67) after carrying out a sensitivity analysis excluding studies in which exposures to exhaust from diesel versus conventional

internal combustion engines could not be easily distinguished. There was also little difference in the pooled RR between occupations (Table 14).

**Table 14** Lung cancer risk in different occupations exposed to diesel engine exhaust (source: Lipsett and Camplemen, 1999)

Occupation	Pooled RR	95%CI
Truck drivers	1.47	1.33-1.63
Railroad workers	1.45	1.08-1.93
Mechanics/garage workers	1.35	1.03-1.78
Heavy equipment operators/dockworkers	1.28	0.99-1.66
Professional drivers/transportation operatives	1.45	1.31-1.60
Diesel exhaust grouped	0.97	0.95-1.00

Since these reviews a number of new studies have been published. In a large record-linkage study from Sweden, (Boffetta *et al*, 2001), men exposed to DEE identified at the 1960 census experienced an increased risk of lung cancer of 1.1 (95%CI=1.1-1.2) and 1.3 (95%CI=1.3-1.4) for medium and high intensity of exposure. The SIR for men (n=6,266) was 1.09 (95%CI=1.06-1.12), and for women (n=57) was 1.09 (95%CI=0.83-1.42).

In an update of a US railroad cohort of 54,973 workers between 1959 and 1996, there was a total of 43,593 deaths including 4351 lung cancer deaths (Garshick *et al*, 2004). Mortality did not increase with increasing years in work, but was elevated in jobs associated with work on trains powered by diesel locomotives.

Steenland *et al*. (1998) compared DEE exposure between 954 cases who died between 1982 and 1983 and 1,085 controls; all were long-term union members enrolled in the pension system of the US trucking industry. DEE exposure was estimated based on a 1990 industrial hygiene survey. All analyses resulted in a significant positive trend in risk with increasing cumulative exposure. A male truck driver exposed to 5µg m<sup>3</sup> of elemental carbon would have a lifetime excess risk of lung cancer of 1-2%, above a background risk of 5%.

Bruske-Hohlfeld *et al*. (1999) pooled two case-control studies on lung cancer in Germany, giving a total of 3,498 cases and 3,541 population-based controls. Information about occupational and smoking history was obtained by questionnaire. Drivers of lorries, buses, taxis, diesel locomotives and fork-lift trucks, bulldozers, excavators, and tractors, were considered as exposed to DEE. Among those ever exposed, the OR was 1.43 (95%CI=1.23-1.47) after adjustment for smoking and asbestos exposure. Higher ORs were seen in cases with more than 10-years work experience. ORs were greater among those hired after 1946 compared to pre-1946. Significant ORs were observed for a number of occupations within the industry:

Occupation	N	OR	95%CI
Professional drivers	337	1.25	1.05-1.47
Other traffic-related jobs	60	1.53	1.04-2.24
Heavy equipment operators	32	2.31	1.44-3.70
Drivers of framing tractors	36	1.29	0.78-2.14

In a Finnish study economically active individuals (as identified by the 1970 census) were followed for lung cancer during 1971-1995 (n=33,664) (Guo *et al*, 2004). The occupation stated at the census was converted to DEE exposure with a JEM. Among men significant SIRs were observed for:

Occupation	N	SIR	95%CI
Mines, quarry workers, metal ore	36	3.26	2.28-4.51
Mines, quarry workers, except metal ore	181	1.85	1.59-2.14
Mines, quarry workers, other	70	1.73	1.35-2.19
Truck drivers	620	1.13	1.04-1.22
Car mechanics	266	1.14	1.01-1.29
Asphalt workers	32	2.25	1.54-3.17
Dockers, stevedores	236	1.32	1.16-1.50

No exposure-response relationship was observed with cumulative exposure for lung cancer overall, but there was a small increase in small cell carcinomas with increasing exposure. Lagging exposures did not affect the exposure-response relationship.

### 2.2.12 Epichlorohydrin

Epichlorohydrin (ECH) is an important industrial chemical widely used as an intermediate for various synthetic products. The evidence for the carcinogenicity of ECH is unconvincing. In two chemical plants of 863 workers with probable exposure to ECH during 1948-1965, they were followed to 1983 (Enterline *et al.*, 1990). There were 14 lung cancer deaths resulting in an SMR of 1.08 (95%CI=0.59-1.82), with the SMR for <20-years since first exposure compared to  $\geq$ 20-years since first exposure being 1.405. In an extension to this study Tsai *et al.* (1996) extended the follow-up to 1993. There were 23 lung cancer deaths giving an SMR of 0.71, with no dose-response relationship by level of exposure.

Sathiakumar and Delzell (2000) studied a cohort of 2,859 men and 407 women who had worked at a dye and resin manufacturing plant between 1952 and 1996. Many of these employees had the potential for exposure to ECH, but in total there were only 89 lung cancer deaths giving a SMR of 1.22 (95%CI=0.98-1.50).

### 2.2.13 Environmental Tobacco Smoke

Many epidemiological studies and reviews have established that environmental tobacco smoke (ETS) is a cause of serious disease in adults and children (SCOTH, 1998, SCOTH, 2004). The prevalence of exposure to ETS amongst men at work in the general workforce is 11%, and women is 4%<sup>7</sup>, and therefore an estimated 1.3 million are exposed. Over a third of these are employed in the wholesale and retail trade and restaurants and hotels. Construction and financing, insurance, real estate and business services also have significant numbers exposed. Meta-analyses of lung cancer in never smokers exposed to ETS at the workplace have found a statistically significant increase in risk of 12-19% (IARC, 2004). It has also been estimated that the general population attributable risk of lung cancer to ETS in the UK is about 0.026 (Jamrozik, 2005).

Zhong *et al.* (2000) carried out a meta-analysis of 35 case-control and five cohort studies providing quantitative estimates of the association between lung cancer and exposure to ETS between 1981 and 1999. Pooled risk estimates were calculated using fixed and random effects models for exposure to ETS from subject's parents (during childhood), spouses and co-workers. For non-smoking women exposed to ETS from their husbands the pooled estimate was 1.20 (95%CI=1.12-1.29). For non-smoking men the pooled RR was 1.48 (95%CI=1.13-1.92) for ever exposed to ETS. In contrast for non-smoking men ever exposed to ETS at work the pooled RR was 1.29 (95%CI=0.93-1.78) whereas for women it was 1.15 (95%CI=1.04-1.28) with an overall risk of 1.16 (95%CI=1.05-1.28).

Brennan *et al.* (2004) pooled data from two large German case-control studies of lung cancer from studies in the USA, Germany, Italy, Sweden, UK, France, Spain and Portugal. Subjects included

<sup>7</sup> <http://www.ash.org.uk/html/factsheets/html/onsworkplacefigures2004.html>

1,263 never smoking lung cancer patients and 2,740 population and hospital controls recruited during 1985-1994. The OR for ever exposure from the workplace was 1.16 (95%CI=0.99-1.36) and for long term exposure was 1.27 (95%CI=1.03-1.57). These results were similar to those for ever exposure to spousal smoking. A significant exposure-response relationship was observed:

<b>Duration of exposure (years)</b>	<b>RR</b>	<b>95%CI</b>
Non-exposed	1.00	
<8.0	1.00	0.80-1.26
8.0-20.9	1.19	0.97-1.46
≥21.0	1.27	1.03-1.57

Boffetta (2002) also carried out a meta-analysis of 59 studies obtaining an overall RR of 1.25 (95%CI=1.15-1.37). In 16 studies that assessed risk from workplace exposure to ETS the pooled RR was 1.17 (95%CI=1.04-1.32), with a slight difference for men (RR=1.23, 95%CI=0.78-1.94) and women (RR=1.17, 95%CI=1.02-1.33).

Jamrozik (2005) investigated deaths from ETS in employees of the hospitality industry as well as in the general UK workforce and population in the year 2003. The RR for lung cancer attributable to ETS was 1.24, with the population attributable risk of 0.026 and attributed deaths numbering 160. However, in the hospitality industry the RR and PAR were higher:

	<b>Pub, bar, nightclub workers</b>	<b>Hotel and restaurant workers</b>
RR	1.73	1.24
PAR	0.422	0.194

IARC (2004) concluded that there is sufficient evidence that involuntary smoking (exposure to second-hand smoke or ETS) causes lung cancer in humans, and is therefore carcinogenic (Group 1). They comment that the various meta-analyses of lung cancer in never smokers exposed to ETS at the workplace have found a statistically significant increased in risk of 12-19%.

### **2.2.14 Formaldehyde**

Formaldehyde exposure in GB occurs mainly amongst workers manufacturing furniture and fixtures, wearing apparel (except footwear), and wood and wood/cork products. Within these industries urea-formaldehyde and phenolic-formaldehyde resins are used primarily as adhesives. A MEL/STEL of 2.5mg/m<sup>3</sup> (8-h TWA) was introduced in the 1990s. In 1995, IARC (1995) concluded that there was limited evidence in humans of the carcinogenicity of formaldehyde, and evaluated it as probably carcinogenic to humans (Group 2A). However, in a later review of the evidence IARC (2006c) concluded that there was now sufficient evidence in humans and evaluated formaldehyde as a Group 1 carcinogen, based on evidence for nasopharyngeal and sinonasal cancers, and leukaemia. The UK WATCH committee have also concluded formaldehyde to be a low potency human carcinogen.

In a study of British chemical workers exposed to formaldehyde, Coggon *et al.* (2003) assembled a cohort of 14,014 men employed after 1937 at six factories where the chemical was produced or used. The cohort was followed over the period 1941 to 2000. In the total cohort there were 594 lung cancer deaths compared to 486.8 expected, giving an SMR of 1.22 (95%CI=1.12-1.32). In the period of 1990-2000 the SMR was slightly lower at 1.16 (95%CI=1.00-1.34). Amongst workers with high exposures, estimated at greater than 2ppm, the SMR was 1.58 (95%CI=1.40-1.78) over the total follow-up period. Compared to national rates a significant exposure-response trend was observed with the risk in the highest exposure category (>2ppm) being 1.58 (95%CI=1.40-1.78). Among men with high exposure the risk was greater in men first employed before 1965, and significantly increased in men with less than 14 years employment.

In the US, a large cohort of 25,619 workers employed in ten facilities producing or using formaldehyde have been followed to 1994 (Hauptman *et al*, 2004). All workers started prior to 1966. At the end of follow-up, 8,486 had died, 6,495 among exposed workers. In total there were 744 lung cancer deaths (SMR=0.94). Among non-exposed workers, based on 103 deaths, the SMR was 0.79 (95%CI=0.65-0.96), whereas among exposed workers, based on 641 deaths, the SMR was 0.97 (95%CI=0.90-1.05). There was no trend with average intensity, peak or cumulative exposure.

In a review of cohort studies published up to 2007, (Bosetti *et al*, 2008), a total of 30 publications were identified, including seven cohorts of industry workers and nine cohorts of professionals. Case-control studies were not included in the analysis because of their unreliable exposure information. In the industry worker cohorts, only four reported lung cancer risk, with a total of 1,459 cases. The summary SMR for these studies was 1.07 (95%CI=1.01-1.12). Among professional workers, the summary SMR was 0.47 (141 cases). However, these figures were not adjusted for smoking. The pooled RR was 1.06 (95%CI=0.92-1.23) in industry workers and 0.63 (95%CI=0.47-0.84) in professionals.

### 2.2.15 Ionising Radiation

Lung cancer risk has been observed to be elevated in patients receiving radiation therapy for ankylosing spondylitis (Smith and Doll, 1982, Weiss *et al*, 1994). Ionising radiation (IR) is a well-established cause of cancer and has been classified as a Group 1 carcinogen by IARC (IARC, 2000), but has only occasionally been associated with lung cancer. A study of men who participated in the UK atmospheric nuclear weapons tests and experimental programmes found a small excess (Darby *et al*, 1988a, Darby *et al*, 1988b, Darby *et al*, 1993a, Darby *et al*, 1993b, Muirhead *et al*, 2003, Muirhead *et al*, 2004). In the cohort 21,357 participants were followed to 1998. Among the cohort 4,902 were known to have died. All-cause (SMR=0.89) and all-cancer (SMR=0.93) mortality were both significantly reduced among test participants (Muirhead *et al*, 2003). Among these there were 480 deaths from lung cancer giving a SMR of 0.85 (95%CI=0.78-0.93) compared to that for controls (Ministry of Defence employees not involved in tests) (SMR ratio=0.96, 95%CI=0.85-1.09). However, the ratio of SMRs for exposure workers to controls in the follow-up period 1991-1998 was 1.10 (95%CI=0.94-1.29). The corresponding RR for lung cancer incidence was 0.94 (95%CI=0.85-1.04).

Airline pilots and flight engineers are occupationally exposed to IR of cosmic origin, the highest doses occurring in jet flights in high altitude and on polar routes (Blettner *et al*, 2003). A study of British Airways (BA) crew members, 6,209 male pilots and 1,153 male flight engineers employed for at least one year between 1950 and 1992 were followed up and compared with the national population (Irvine and Davies, 1999). At the end of the study period, 592 pilots and 127 flight engineers were known to have died. For pilots and flight engineers the all cause and all cancer mortality were significantly reduced. Forty-three lung cancer deaths were observed among pilots whereas 103 were expected (SMR=0.415, 95%CI=0.300-0.558). For flight engineers 20 lung cancer deaths were observed with 20.45 expected (SMR=0.816, 95%CI=0.499-1.261). Cancer risk was greater among pilots and flight engineers on long haul flights compared to short haul, the rate ratios being 1.80 (95%CI=0.95-3.30) and 2.48 (95%CI=1.30-4.49), respectively. A European-wide study of crews from nine countries, including an update of the BA cohort (7,770 employed between 1950 and 1997), found 153 lung cancer deaths (307.7 expected) giving an SMR of 0.53 (95%CI=0.44-0.62) (Blettner *et al*, 2003). Poisson regression analysis of risk by duration of exposure showed a significant trend of rate ratios of 1.0, 0.98, 1.07, 0.89 for duration of <10, 10-<20, 20-<30, 30+ years, respectively. The typical annual exposure of aircraft crew in this study was between 2 and 6mSv.

Physicians joining the British radiological society before 1921 have been observed for over 100 years (Berrington *et al*, 2001, March, 1944). Berrington *et al*. (2001) reported results of a follow-up to 1997 of those who had registered between 1897 and 1979. Mortality risk from all cancers was 0.73 (95%CI=0.64-0.83) when compared to the national population, whereas when compared to other medical practitioners it was 1.16 (95%CI=1.02-1.32). Since 1920 there were 25 deaths from lung cancer (20+ years after registration) compared to 35.84 expected giving an SMR of 0.70 (95%CI=0.45-1.03). When compared to rates for medical practitioners the SMR was 0.89. Risk in

those first registered in 1897-1920 (2.46) was greater than in those first registered in 1921-1935 (1.06) and has declined further since.

A similar study of 71,894 US radiologic technicians, who were certified during 1926-1982, followed them to 1998 (Rajaraman *et al*, 2006). A total of 287 lung cancer cases were identified (66 incident and 221 decedents). Smoking was significantly related to lung cancer risk. No relationship was observed with year first worked, number of years worked or age first worked.

Nuclear industry workers provide an opportunity to investigate any effect of internally deposited radionuclides. Smith and Douglas (1986) investigated the mortality of all 14,327 people who were known to have been employed at the Sellafield plant of British Nuclear Fuels (BNFL) at any time between 1947 and 1975, and followed up to 1983. A total of 2,277 were known to have died, 572 from cancer (SMR=0.95, 95%CI=0.87-1.03). Among all workers 205 deaths were from lung cancer giving an SMR of 0.90 (95%CI=0.78-1.03) based on national rates and 1.04 based on local rates, 147 of these deaths were among radiation workers resulting in a SMR of 0.87 (95%CI=0.73-1.02). Among radiation workers no trend was observed with radiation dose. A subsequent report obtained similar results (Douglas *et al*, 1994). In the most recent study Omar *et al*. (1999) assessed the health of 14,319 workers and followed them for mortality to 1992, and for cancer incidence between 1971 and 1986. A total of 3,854 (men: 3,411; women: 445) were known to have died, 2,682 among radiation workers (1,345 plutonium workers, 1,337 other radiation workers) and 1,172 among other workers. There were 738 cancer deaths resulting in a SMR of 0.96 (95%CI=0.89-1.03) compared to the national population and 0.97 (95%CI=0.90-1.04) compared to the local population. Table 15 gives the lung cancer mortality among different workers.

**Table 15** Lung cancer mortality among different workers within the UK nuclear industry (source: Omar *et al.*, 1999)

	Number observed/expected	SMR	
		Compared to national population	Compared to local population
All workers	338/381.35	0.89	0.96
Radiation workers	246/286.87	0.86	
Plutonium	133/145.78	0.91	
Other	113/141.09	0.80	
Non-radiation	92/94.37	0.97	
Plutonium vs Other		1.12	
Radiation vs Non-radiation		0.98	

No exposure-response relationship was observed between lung cancer risk and external radiation dose.

A total of 489 incidence cancers were observed (254 among plutonium workers and 235 other radiation workers). A total of 140 lung cancer cases were observed (SRR=0.87, 95%CI=0.73-1.02), with 81 among plutonium workers (SRR=0.95, 95%CI=0.75-1.18) and 59 among other radiation workers (SRR=0.78, 95%CI=0.59-1.00). No exposure-response relationship was observed.

Prior to the most recent analysis the Sellafield cohort was combined with cohorts from the UK Atomic Energy Authority (UKAEA) and the Atomic Weapons Establishment (AWE) (Carpenter *et al.*, 1994, Carpenter *et al.*, 1998). The first study looked at mortality among all 75,006 employees of the three establishments between 1946 and 1988. A total of 13,505 were known to have died, with 3,745 cancer deaths (men: 3,077; women: 668) resulting in a SMR of 0.84 (95%CI=0.82-0.87). There were 1,201 lung cancer deaths among all workers (SMR=0.77, 95%CI=0.73-0.82), with 641 amongst radiation monitored workers (SMR=0.74, 95%CI=0.68-0.79) and 560 among other workers (SMR=0.82, 95%CI=0.76-0.89). The second paper examined the monitored workers in more detail. In individuals ever monitored for tritium, plutonium or other radionuclides, the SMR was well below one (maximum 0.86), as was that for individuals not monitored the SMR was 0.68.

In an extension to the analysis, the National Registry for Radiation Workers (NRRW) was set up (Kendall *et al.*, 1992, Little *et al.*, 1993, Muirhead *et al.*, 1999). The initial analyses included workers from AWE, BNFL, Ministry of Defence, Nuclear Electric, and the then UKAEA. The most recent study included workers from Central Laboratory of the Research Councils, the Medical Research Council Radiobiology Unit, the National Radiological Protection Board, Nycomed Amersham plc, Rolls-Royce and Associates Ltd., and Scottish Nuclear Ltd. In total there were 124,743 workers with a range of exposures and a mean dose of 30.5mSv. There was a total of 12,765 deaths (SMR=0.82, 95%CI=0.81-0.84), and 3,598 cancer deaths (SMR=0.82, 95%CI=0.79-0.85). There were 1,132 lung cancer deaths (SMR=0.71, 95%CI=0.67-0.76). In a lagged analysis (10-years) the SMR was the same. No exposure-response relationship was observed

In an IARC sponsored analysis, the three UK cohorts were combined with three from the USA and one from Canada (Cardis *et al.*, 1995). This resulted in a mortality analysis on 95,673 workers (85.4% men) monitored for external exposure to IR and employed for at least six months. There were a total of 15,825 including 3,976 from cancer. There were 1,238 lung cancer deaths with 1,238 expected (SMR=1.00, 95%CI=0.91-1.06).

In an update of this study a further 12 countries were included in the analysis with a total of 154 facilities included (Cardis *et al.*, 2005). There were a total of 407,391 workers, with over 5 million

person-years. There were a total of 24,158 deaths, 6,519 cancer deaths (excluding leukaemia); however, lung cancer results were not presented.

### 2.2.16 Lead

Lead was originally classified as a Group 2B carcinogen (IARC, 1987), but a more recent working group re-evaluated it to 2A (IARC, 2006a). Almost all of the information regarding lead exposure and cancer is derived from studies of lead workers and involves exposure to inorganic lead. Several reviews have been published on this topic (ATSDR, 2005a, IARC, 2006a, Landrigan *et al*, 2000, Silbergeld *et al*, 2000, Silbergeld, 2003, Steenland and Boffetta, 2000).

In an early study of UK lead-exposed workers involved in the manufacture of batteries, 754 individuals, who had died, from a population of 1,898 pensioners from four lead acid battery factories during 1925 to 1976 were studied (Malcolm and Barnett, 1982). In addition the deaths of 553 individuals that occurred before retirement were also studied. However, they observed no excess lung cancer risk. A subsequent study of workers from the same manufacturing facilities found no association between lead exposure and deaths from malignant neoplasms, either in general or for specific cancer sites (Fanning, 1988).

In the USA there has been an extended study of lead battery and lead smelter workers (Cooper and Gaffey, 1975, Cooper, 1976, Cooper *et al*, 1985, Wong and Harris, 2000). In the most recent study, vital status was ascertained between 1947 and 1995 for 4,518 workers at lead battery plants and 2,300 lead smelters. Exposure was assessed by urinary and blood lead levels and showed that smelter workers had higher urinary and blood levels. There were 3,713 deaths, 2,613 among battery workers and 1,100 among smelter workers, giving an overall SMR of 1.05 (95%CI=1.01-1.08). There were 897 cancer deaths (SMR=1.04, 95%CI=0.97-1.11), including 317 from lung cancer giving an SMR of 1.16 (95%CI=1.04-1.30). Among battery workers there were 210 deaths from lung cancer giving an SMR of 1.14 (95%CI=0.99-1.30), whereas among smelter workers there were 107 resulting in an SMR of 1.22 (95%CI=1.00-1.47). In both groups, workers hired after 1946 were at a significant excess risk of lung cancer (SMR=1.35), which was significantly greater than that of workers hired before 1946 (SMR ratio=1.31, 95%CI=1.04-1.64). The SMR ratio was significant for battery workers (1.55, 95%CI=1.16-2.07), but not for smelter workers. Mortality was significantly increased in workers employed for 10-19 years (SMR=1.45, 95%CI=1.08-1.89) and 20-34 years of latency (SMR=1.38, 95%CI=1.15-1.65).

In another US study of 1,990 smelter workers employed for at least one year between 1940 and 1965, vital status was ascertained to 1979 (Selevan *et al*, 1985, Steenland *et al*, 1992). There were 1,028 deaths, 192 from cancer, and 72 from lung cancer (SMR=1.18, 95%CI=0.92-1.48). Among a sub-cohort of 1,436 with high lead exposure there were 49 deaths (SMR=1.11, 95%CI=0.82-1.47). Mortality from lung cancer appeared to decrease with duration of exposure.

In a Swedish study of 3,979 smelter workers employed for at least one year during 1928-1979, a sub-cohort of 1,992 workers employed in lead-exposed departments was formed (Gerhardsson *et al*, 1986, Lundstrom *et al*, 1997). Mortality was assessed in 1955-1987 and cancer incidence in 1958-1987. Overall lung cancer incidence was significantly increased (SIR=2.8, 95%CI=2.1-3.8) and in the group with the highest exposure the risk was slightly higher (SIR=3.1, 95%CI=2.0-4.6). Workers hired before 1950 had higher risk estimates (SIR=3.6, 95%CI=2.6-5.0) than the workers hired later (SIR=1.3, 95%CI=0.6-2.6). In a further analysis of the cohort (Englyst *et al*, 2001) two sub-cohorts were defined: (1) 710 workers employed in lead and other departments during work history; and (2) 383 workers from sub-cohort 1 only employed in lead department. In both groups the incidence of lung cancer was significantly increased, 2.40 (95%CI=1.20-4.50) and 3.60 (95%CI=1.20-8.30), respectively. In a nested case-control study from this cohort of 46 cases and 141 matched controls, among smokers, the cumulative air arsenic exposure index, but not the lead exposure indices, was significantly higher among the cases (Lundstrom *et al*, 2006). Thus, this study indicates lead exposure may not be a risk factor in this cohort.



In Italy, 1,388 male smelter workers employed for at least one year between 1932 and 1971, were followed from 1950 to 1992 (Cocco *et al.*, 1997). However, lung cancer mortality was reduced at 0.62 (95%CI=0.43-0.80) when compared to national rates and 0.82 (95%CI=0.56-1.16) when compared to regional rates.

Mortality was also investigated in a UK cohort of men employed at a zinc-cadmium smelter (Ades and Kazantzis, 1988). The study consisted of all hourly-paid workers employed in 1943 and those who subsequently started work before 1970, and employed for at least one year. The SMR for lung cancer was 1.25 (95%CI=1.07-1.44), and was positively related to duration of employment. In a matched nested case-control study the cumulative arsenic and lead exposure, but not cadmium, were positively related to lung cancer mortality.

Two meta-analyses have been undertaken to investigate the link between lung cancer and occupational exposure to inorganic lead. Fu and Boffetta (1995) reviewed case-control and cohort studies of workers in several industries (battery, smelter, pigment, printing, glassworks) published since 1963. For lung cancer, 15 studies were included in the analysis giving a pooled RR of 1.24 (95%CI=1.16-1.33). However, there was significant heterogeneity between the studies. Using a random-effects approach resulted in a pooled RR of 1.29 (95%CI=1.10-1.50). In four studies of heavy exposure to lead the pooled RR (fixed-effects) was 1.44 (95%CI=1.29-1.62), which reduced to 1.42 (95%CI=1.05-1.92) when a random-effects approach was used.

More recently, Steenland and Boffetta (2000) considered eight studies with high documented exposures, none of which controlled for smoking. The results showed significant heterogeneity due to high RR in the Swedish study of Lundstrom *et al.* (1997). Using a random-effects model gave a pooled RR of 1.30 (95%CI=1.15-1.46). However, taking out the Lundstrom study and using a fixed-effects model resulted in a pooled RR of 1.14 (95%CI=1.04-1.25). The authors concluded the studies show only a weak evidence of effect, and heterogeneity and possible confounding limited interpretation.

### **2.2.17 Mineral Oils (untreated and mildly treated)**

Mineral oils are used in a variety of occupational settings and applications. Those in which inhalation exposure occurs include metalworking, print press operations and cotton and jute spinning.

Numerous studies have been carried out on workers exposed to mineral oils. In a review by Tolbert (1997), findings presented at the IARC (IARC, 1984b) review were summarised and findings of studies reported in the 10-years since the publication were presented. Case-control studies have tended to show associations (some significant) between lung cancer risk and mineral oil exposure in the metalworking (1984) and in the printing industries (1987). However, cohort studies of mineral oil exposure in metalworkers have generally shown no excess risk for lung cancer although excess risks have been found in cohort studies of printers.

In a comprehensive and systematic review by NIOSH (1998) no excess lung cancer risk was consistently observed among exposed workers. Results from Eisen *et al.* (2001) show no evidence of an increased risk of lung cancer with exposure to any class of MWF (straight, soluble, synthetic) among 46,399 automobile manufacturing workers with potential exposure to MWFs. An earlier case-control study within the cohort suggested an inverse relationship for synthetic MWFs. Some studies have observed some increased risks (Siemiatycki *et al.*, 1987) but the majority of the literature tends to corroborate a lack of an association between MWFs and lung cancer (Calvert *et al.*, 1998, NIOSH, 1998).

### 2.2.18 Mustard Gas

In a GB study of a cohort of 2,498 men and 1,032 women employed in the manufacture of mustard gas during the second world war, 95% were successfully traced to 1984 (Easton *et al*, 1988). There were 2,130 deaths (1,655 men, 475 women), of which 200 were from lung cancer, giving an SMR of 1.45 (95%CI=1.25-1.66) based on national rates, whereas the SMR was 1.62 (95%CI=1.40-1.86) based on local rates. Among men there were 189 deaths giving an SMR of 1.48 (95%CI=1.28-1.72). Mortality was greater in those with more than three years employment (SMR=1.74, 95%CI=1.40-2.14) compared to those with less than three years (SMR=1.32, 95%CI=1.07-1.60).

### 2.2.19 Nickel and Nickel Salts

Nickel and Nickel Salts are mainly used in the production of stainless steel, non-ferrous alloys, electroplating, and in the manufacture of batteries (IARC, 1990). A MEL of 0.5mg/m<sup>3</sup> (8-h TWA) was set for nickel metal in 1992, and 0.1 mg/m<sup>3</sup> (8-h TWA) for water-soluble nickel compounds.

A large number of epidemiology studies have assessed the carcinogenic potential of nickel; it has been estimated that over 100,000 nickel workers have been examined in epidemiology studies (Seilkop and Oller, 2003). These workers have been employed in nickel refinery facilities, nickel mining and smelting facilities, nickel alloy production facilities, stainless steel production facilities, nickel-cadmium battery production facilities, or as stainless steel welders. In the mid 1980s, a committee of epidemiologists was formed to investigate the human health risks associated with nickel exposure and to determine the specific forms of nickel that are associated with an increased risk of respiratory cancer (ICNCM, 1990). The investigators updated the existing data from 10 previously examined cohorts and estimated levels of exposure to various nickel species. Since no measurements of nickel concentrations were available for workers employed prior to 1950, the investigators estimated total nickel exposure levels using recent monitoring data and historical data on the industrial processes. Based on information on the chemistry of the industrial process, total nickel exposure levels were divided into exposure to four nickel species: soluble nickel (including nickel sulphate and nickel chloride), sulphidic nickel (including nickel sub-sulphide), oxidic nickel, and metallic nickel. It was noted that interpretation of the results of many of the epidemiology studies of nickel workers is confounded by poor nickel exposure characterization, exposure to relatively high concentrations of other metals, including arsenic, and in some cases, exposure to irritant gases including hydrogen sulphide, ammonia, chlorine, and sulphur dioxide (IARC, 1990).

Statistically significant increases in the risk of lung cancer were found among nickel refinery workers (Andersen *et al*, 1996, Anttila *et al*, 1998, Chovil *et al*, 1981, Doll *et al*, 1977, Enterline and Marsh, 1982b, Grimsrud *et al*, 2003, ICNCM, 1990, Karjalainen *et al*, 1992, Magnus *et al*, 1982, Muir *et al*, 1994, Pedersen and Andersen, 1973, Peto *et al*, 1984, Roberts *et al*, 1989)). In general, the nickel refinery workers were exposed to high levels of sulphidic and oxidic nickel and low levels of soluble and metallic nickel (ICNCM, 1990). At one nickel refinery facility (New Caledonia), the risk of respiratory tract cancers was not significantly elevated in the nickel-exposed workers (Goldberg *et al*, 1987, Goldberg *et al*, 1994, ICNCM, 1990). This refinery facility differs from other refineries in that the workers were primarily exposed to silicate oxide ore and oxidic nickel with very little exposure to sulfidic or soluble nickel. Sunderman *et al*. (1989) examined the histopathological diagnosis of 259 cases of lung cancer among workers at three nickel refinery facilities. The lung cancers were primarily squamous cell carcinomas (67%), anaplastic, small cell, and oat cell carcinomas (15%), and adenocarcinomas (8%). The types of lung cancers were similar to those found in the general population, suggesting a lack of nickel-specific tumor types.

In contrast to the findings of nickel refinery workers, most studies in other groups of nickel workers have not found significant increases in the risk of lung cancer among workers employed in nickel mining and smelting facilities (Shannon *et al*, 1984, Shannon *et al*, 1991), workers employed at a hydrometallurgical refinery (Egedahl *et al*, 1991, Egedahl *et al*, 2001), workers employed at nickel alloy and stainless steel production facilities (Cornell and Landis, 1984, Cornell, 1984, Cox *et al*,

1981, Enterline and Marsh, 1982b, ICNCM, 1990, Jakobsson *et al*, 1996, Moulin *et al*, 1993a, Sorahan, 2004), workers employed as stainless steel welders (Danielsen *et al*, 1996, Gerin *et al*, 1993, Hansen *et al*, 1996, Simonato *et al*, 1991), workers involved in nickel-chromium electroplating (Pang *et al*, 1996), or workers employed at a barrier production facility (Cragle *et al*, 1984, Godbold and Tompkins, 1979, ICNCM, 1990). Although some studies of these workers did find significant increases in respiratory tract cancers (Becker, 1999, Moulin *et al*, 1990), the increased risk was attributed to exposure to other carcinogenic agents, such as polycyclic aromatic hydrocarbons or asbestos. Redmond (1984) and Arena *et al*. (1998) reported significant increases in lung cancer risks among high nickel alloy production workers as compared to the U.S. population. However, when the local population was used as the comparison group, the increase in lung cancer risk was no longer statistically significant (Arena *et al*, 1998). In general, workers employed in these industries were exposed to lower levels of sulfidic or oxidic nickel than the nickel refinery workers who were primarily exposed to metallic nickel (Cragle *et al*, 1984, Godbold and Tompkins, 1979) or soluble nickel (Pang *et al*, 1996).

Because nickel workers are exposed to several nickel species, it is difficult to assess the carcinogenic potential of a particular nickel species. The ICNCM (1990) investigators used cross-classification analyses to examine the exposure-response to a specific nickel species independent of variations in other species. The most comprehensive cross-classification analyses were performed for cohorts of workers in different departments at the Mond/INCO (Clydach) nickel refinery and at the Falconbridge (Kristiansand) nickel refinery (only analyzed for metallic nickel). The strongest evidence of carcinogenicity of a particular nickel species is for sulphidic nickel. The highest cancer risk levels were found in cohorts with the highest sulphidic nickel exposure levels, although high oxidic and soluble nickel levels were also found at these same facilities. The increased cancer risks in workers with high sulphidic nickel exposure and low oxidic and soluble nickel exposure suggests that sulphidic nickel is the causative agent. The evidence for oxidic nickel is weaker. No differences in cancer risks were seen among groups of workers with low sulphidic and soluble nickel exposures when the levels of oxidic nickel were varied. However, when high soluble nickel levels are present, oxidic nickel appears to be carcinogenic. The available weight of evidence does not suggest that exposure to soluble nickel, in the absence of carcinogenic compounds, will increase the risk of cancer. At low sulphidic and oxidic nickel levels, increasing soluble nickel levels do not increase the cancer risk in the UK Clydach cohort (see below). However, at high oxidic nickel levels, increasing the soluble nickel levels resulted in at least a 2-fold increase in the cancer risk. There is no evidence that metallic nickel is associated with increased lung cancer risks in nickel workers. The ICNCM (1990) concluded that lung cancer was related primarily to exposure to less soluble nickel compounds at concentrations of  $\geq 10$  mg Ni/m<sup>3</sup> (primarily oxidic and sulphidic compounds). Exposure to soluble nickel compounds at concentrations of  $>1$  mg Ni/m<sup>3</sup> appeared to enhance the carcinogenicity of insoluble nickel compounds.

In the recent updates of the UK Clydach refinery cohort, 812 workers first employed between 1953 and 1992 who had at least five years' employment, were followed between 1958 and 2000 (Sorahan and Williams, 2005). A total of 191 deaths were observed whereas 198.3 were expected (SMR=0.96, 95%CI=0.83-1.11). There were 63 cancer deaths of which 28 were lung cancer (SMR=1.39, 95%CI=0.92-2.01). There was a significant trend with time since starting employment and all lung cancer deaths occurred among those starting before 1972. Sixteen of the cases smoked, which resulted in a significant excess risk (SMR=2.36, 95%CI=1.35-38.3). Workers involved in feed handling of nickel extraction were at a significant excess risk at 2.31 (95%CI=1.06-4.39). Those involved in pellet and powder production, nickel salts and derivatives were also at an excess risk.

In another analysis, Grimsrud and Peto (2006) investigated mortality in workers first employed at the refinery between 1930 and 1992, and followed then to 2000. Over this whole period the SMR, based on 62 deaths, was 1.33 (95%CI=1.03-1.72).

Sorahan (2004) also examined the mortality experience of 1,999 workers employed at a plant manufacturing nickel alloys. Similar to the Clydach cohort, all workers were first employed between

1953 and 1992 for at least five years, and followed to 2000. A total of 557 deaths were observed, 169 cancers, and 64 lung cancers, which resulted in an SMR of 0.87 (95%CI=0.67-1.11).

## 2.2.20 Polycyclic Aromatic Hydrocarbons

PAHs are a complex and important group of chemicals formed during the incomplete combustion of organic material. PAHs are widespread in the environment, diet and tobacco smoke being two important sources of exposure, occurring as a complex mixture of variable composition making the assessment of risk from individual PAHs difficult. Exposure occurs in a number of industries and occupations including use of coke ovens, coal gas production, aluminium smelting, carbon anode plants, asphalt use, tar distillation, occupation as a chimney sweeps, in thermoelectric power and carbon black industries. The British industries (according to CAREX) which have the greatest number personnel exposed (total=106,285) include the manufacture of wearing apparel, except footwear (7.9%), manufacture of transport equipment (8.7%), land transport (8.8%) and sanitary and similar services (8.9%). Studies of workers in these industries, especially coke ovens and aluminium smelters, have shown clear excesses of lung cancer (Boffetta *et al.*, 1997, IARC, 1984a, IARC, 1984b, IARC, 1984c, IARC, 1985, Mastrangelo *et al.*, 1996). In aluminum smelting there are differences in cancer risk according to the process used (Soderberg versus pre-baked anode). Although there is no doubt about the risk of lung cancer with exposure to PAHs, there is uncertainty whether a dose-response relationship exists, and thus the risks posed at today's levels in the workplace and general environment.

Mastrangelo *et al.* (1996) reviewed epidemiological studies reporting direct evidence of the carcinogenic effects of PAHs in occupationally exposed subjects. An exposure-response relationship was observed between lung cancer risk and exposure as measured as benzene soluble matter (BSM), benzo(a)pyrene (BaP) or PAHs. The overall findings suggested exposure at 0.2mg/m<sup>3</sup> of BSM (which indicates PAH exposure) for 40 years gives a RR of 1.2-1.4 for lung cancer.

In a comprehensive review by Boffetta *et al.* (1997) the authors concluded the lung seems to be the major target organ of PAH carcinogenicity and the increased risk is present in many industries and occupations.

A review and meta-analysis estimated several meta-RRs based on different industries (Armstrong *et al.*, 2004). Thirty-nine cohorts were included in the review. The average estimated unit RR (URR) at 100µg/m<sup>3</sup>-years BaP was estimated to be 1.20 (95%CI=1.11-1.29) and was not sensitive to particular studies or analytic methods. However, the URR varied by industry (Table 16).

**Table 16** Relative risks at 100 µg/m<sup>3</sup> BaP years; from Armstrong *et al.* (2004)

Industry	Mean Unit Relative Risk (95%CI)
Coke ovens	1.17 (1.12-1.22)
Gas workers	1.15 (1.11-1.20)
Aluminium smelter	1.16 (1.05-1.28)
Above 3 combined	1.17 (1.12-1.22)
Carbon anode	4.30 (0.81-22.79)
Asphalt	17.50 (4.21-72.78)
Tar distillery	12.28 (0.48-314.4)
Chimney sweep	16.24 (1.64-160.7)
Power	>1000 (0->1000)
Carbon black	0 (0->1000)

Bosetti *et al.* (2007) also reviewed the results from cohort studies on workers exposed to PAHs in various industries. To obtain a quantitative overall estimate the observed and expected number of deaths/cases in each study were summed and the overall SMR calculated as an un-weighted ratio.

Pooled RRs and the corresponding 95% CIs were computed as a weighted average of the SMR/SIR, using the inverse of the variance of the logarithm of the SMR/SIR as weight. The results of this analysis are given in Table 17.

**Table 17** SMR and pooled RR for exposure to PAHs in various industries and occupations (source: Bosetti *et al.*, 2007)

Industry	No. of cohorts	SMR	Pooled RR* (95%CI)
Aluminium production	8	1.01	1.03 (0.95-1.11)
Coal gasification	4	2.14	2.29 (1.98-2.64)
Coke production	10	1.49	1.58 (1.47-1.69)
Iron and steel foundry	9	1.39	1.40 (1.32-1.49)
Tar distillation	3	1.19	1.21 (0.95-1.55)
Creosote	2	1.11	1.14 (0.85-1.51)
Roofers	2	1.50	1.51 (1.28-1.78)
Asphalt workers	2	1.12	1.14 (1.07-1.22)
Carbon black production	2	1.21	1.30 (1.06-1.59)
Carbon electrode manufacture	6	0.96	1.00 (0.82-1.23)

\* Weighted average of the study SMRs, using the inverse of the variance as weight

### 2.2.21 Radon and its decay products

Occupational exposure to radioactive radon and its progeny occurs in underground mining for uranium and other metals, and in processing ores and radioactive materials. Very few workers in metal ore mining are exposed in GB (probably because there is very little mining now). It is estimated about 560,000 workers are exposed to radon and its decay products in GB, through working in sites located in areas of high radon exposure.

In a mortality study of tin miners in Cornwall, an area of GB with known exposures to radon gas, 3,010 employees of two mines employed between 1941 and 1984 were followed to 1986 (Hodgson and Jones, 1990, Hodgson and Jones, 1991). There were 105 cancers of the trachea, bronchus, lung and pleura resulting in an SMR of 1.58 (95%CI=1.29-1.91). A significant exposure-response relationship was observed with the time spent underground as seen in Table 18.

**Table 18** Lung cancer risk among tin miners by cumulative time underground (source: Hodgson and Jones, 1990)

Time underground (years)	N	SMR	95%CI
0 (surface workers)	8	0.83	0.36-1.64
<5	15	0.91	0.51-1.50
5-10	14	1.72	0.94-2.88
10-20	21	1.76	1.09-2.70
20-30	17	3.56	2.07-5.69
>30	15	4.47	2.50-7.36

SMR was shown to increase with increasing time from final exposure, reaching a maximum around 10-years from final exposure and then declining.

There have been 11 other cohort studies of miners in relation to radon exposure that have been carried out around the world that were reviewed by IARC. These have been of tin, iron, fluor spar and uranium mines. Data from all studies were compiled by Lubin *et al.* (1995) and the Committee on Health Risks of Exposure to Radon (BEIRVI) (1998). The original data from the studies was pooled to include 65,000 men and more than 2,700 lung cancer deaths. The RR relationship from cumulative radon progeny exposure was consistently linear in the range of exposures experience by miners. The exposure-response trend for never-smokers was three times the trend for smokers, indicating a greater RR for exposure in never smokers. The RR from exposure diminished with time since the exposure

occurred. For the same level of exposure, exposures of long duration (+ low rate) were more harmful than exposures of short duration (+high rate). The authors concluded that about 40% of all lung cancer deaths may be due to radon progeny exposure.

Non-occupational exposures to radon have been shown to cause lung cancer in the general population. Darby and colleagues (2006) analysed information collected on 7,148 people with lung cancer, and 14,208 people without lung cancer, from 13 epidemiological studies in Europe. A clear association was observed between lung cancer risk and residential radiation exposure during the previous 35 years. They estimated the excess RR of lung cancer as 0.08 (95%CI=0.03-0.16) for a 100Bq/m<sup>3</sup> increase in the time-weighted average observed radon concentration. The exposure-response relationship was linear with no evidence of a threshold, and it remained significant when only people with observed radon concentrations of <200Bq/ m<sup>3</sup> were included.

### **2.2.22 Inorganic acid mists containing sulphuric acid**

An increased risk has been suggested in workers exposed to strong inorganic acid, e.g. sulphuric acid, in a number of industries, including production of isopropanol and ethanol, steel pickling, battery manufacture and sulphuric acid production, and manufacture of soaps and detergents. Approximately 42,000 workers are exposed to strong inorganic acid mists in GB, mainly in the manufacture of industrial chemicals, fabricated metal products, electrical machinery, and in non-ferrous metal basis industries. The Scientific Committee for Occupational Exposure Limits (SCOEL) recommended an occupational exposure limit (OEL) (Indicative Occupational Exposure Limit Value (IOELV)) of 0.05 mg/m<sup>3</sup> (8-h TWA) with short-term exposure limit (STEL) of 0.1 mg/m<sup>3</sup>.

Steenland and Beaumont (1989) followed a cohort of 1,165 steelworkers exposed to acid mists in pickling areas. All subjects had worked for at least six months with at least one day of work before 1965. The cohort was initially established by NIOSH (Beaumont *et al*, 1987), and followed to 1981, and the analysis by Steenland and Beaumont extended the follow-up to 1986. There were 41 lung cancer deaths observed, giving an SMR of 1.56 (95%CI=1.12-2.11). For those with 20 years or more since first exposure the SMR was 1.72 (95%CI=1.21-2.39). Regression analysis was undertaken to adjust for smoking, and this reduced the SMR for the whole cohort to 1.36 (95%CI=0.97-1.84). These results are in general agreement with the previous analysis, which also showed a higher risk in those exposed to acids other than sulphuric acid.

A cohort study was also carried out at two battery plants and two steel works in Britain (Coggon *et al*, 1996). Each cohort member (n=4,401) was followed up to 1993, of whom 1,277 were known to have died. The cohort was divided into three groups: (a) never exposed to acid mists (n=1,356); (b) possibly exposed (n=367); and (c) definitely exposed (n=2,678). There were 134 deaths from cancer of the lung, pleura and mediastinum in the whole cohort, 36 among those never exposed and 83 among definitely exposed. The resultant SMRs were 0.94 (95%CI=0.78-1.11), 0.77 (95%CI=0.54-1.07) and 0.98 (95%CI=0.78-1.22), respectively.

In another UK study, Sorahan *et al*. (1998) investigated lung cancer mortality among workers exposed to chromic acid mist. Among chrome bath workers there were 49 male lung cancer deaths, whereas 39.11 were expected, resulting in an SMR of 1.25 (95%CI=0.93-1.66), and 16 female deaths (SMR=1.24, 95%CI=0.71-2.01). Among men lung cancer risk was significantly related to the cumulative duration of chrome bath work, the risk at more than five years work being 3.75 (95%CI=1.80-6.89). Poisson regression analysis of lung cancer risk indicated a significant positive trend (p<0.05) between duration of chrome bath work and risk after adjustment for various factors, excluding smoking.

Sathiakumar and colleagues (1997) carried out a review of the relationship between mists containing sulphuric acid and lung cancer risk. The review identified 35 studies, although few were designed with acid mists as the principal exposure under investigation. Exposure assessment in all studies was also limited. The study highlighted the potential for sulphuric acid mist exposure among industrial workers:

High	Sulphuric acid production; isopropanol production; metal pickling
Moderate	Soap and detergent production; ethanol production; nitric acid production
Low	Phosphate fertiliser production, copper and zinc refining; lead battery production.

However, the review concluded that the available evidence failed to show a relationship exists between mists containing sulphuric acid and lung cancer. Of the 12 studies that examined the relationship, nine had lung cancer SMRs ranging from 1.18 to 1.39. These associations could be explained by confounding by smoking and/or occupational exposures other than acid mists.

### 2.2.23 Talc containing asbestiform fibres

In IARC's 1987 review talc was separated into those containing and not containing asbestiform fibres (IARC, 1987). It concluded there is sufficient evidence for the carcinogenicity of talc containing asbestiform fibres (IARC, 1987) based on a series of studies conducted in the populations of talc workers in New York State. However, there was inadequate evidence for the talc not containing asbestiform fibres (Group 3).

Wild (2006) carried out a review of the epidemiological evidence investigating lung cancer risk and talc exposures. A total of ten studies were identified, and exposed populations were divided into three groups:

- Populations in which no other occupational carcinogen was mentioned (only talc millers satisfied this criteria);
- Populations of talc miners exposed to talc, quartz, and/or radon; and
- Other industrial populations in which talc is associated with quartz, nitrosamines, and asbestos depending on the study.

No excess risk was observed among talc millers, where the pooled RR was 0.92 (95%CI=0.67-1.25), whereas an excess was seen among talc miners, pooled RR of 1.20 (95%CI=0.86-1.63) (random-effects: pooled RR=1.85, 95%CI=0.68-5.05). Thus among millers no excesses were observed despite their high exposure experience.

### 2.2.24 TCDD (2,3,7,8-tetrachlorodibenzo-para-dioxin)

TCDD is a member of polychlorinated dibenzodioxins, a group of halogenated organic compounds collectively known as dioxins, that are significant because they act as environmental pollutants. TCDD is the most toxic dioxin, and became well known as a contaminant of Agent Orange, a herbicide used in the Vietnam War and when residents of Seveso, Italy, were exposed following a factory explosion in 1976 (Bertazzi *et al*, 2001). TCDD has no known commercial applications, but it is used as a research chemical. TCDD may be formed during the chlorine bleaching process used by pulp and paper mills, and as a contaminant in the manufacturing process of certain chlorinated organic chemicals, such as chlorinated phenols and the herbicide 2,4,5-T. TCDD, and CDD's in general, are primarily released into the environment during combustion of fossil fuels and wood, and during incineration processes (although levels are extremely low). A recent report suggested potential dioxin production occurred at metal recycling sites, during cement manufacture, at municipal waster incinerators and landfill sites and during the use of thermal oxygen lances (Sweetman *et al*, 2004). A previous study also showed emissions occurred during coke production; the combustion of coal, waste oil, wood, straw, tyres, chemical and clinical waste; in sinter plants; manufacture of non-ferrous metals, lime, glass, ceramics, halogenated chemicals and pesticides (Eduljee and Dyke, 1996).

IARC have concluded the strongest evidence for the carcinogenicity of TCDD is for all cancers combined rather than for any specific site (IARC, 1997a), and was based on four highly exposed cohorts. The carcinogenicity of TCDD has been assessed in numerous case-control and mortality

cohort studies of chemical manufacturing and processing workers, and phenoxy-herbicide and chlorophenol applicators. However, epidemiological studies published since 1997 do not provide concrete evidence concerning the alleged human carcinogenicity of TCDD (Cole *et al*, 2003).

Numerous studies have examined occupational groups and those accidentally exposed to TCDD and other dioxins, but as it is a contaminant of industrial processes it is difficult to measure directly from these processes. Following the industrial accident in Seveso, Italy in 1976 when substantial quantities of TCDD were vented directly into the atmosphere, the local population affected there have been extensively studied. The most recent has followed-up the population for 25-years and observed no increase in all-cause and all-cancer mortality (Consonni *et al*, 2008). Previous studies have shown after 20-years follow-up the risk for lung cancer was non-significantly elevated in the population of the highest exposed zone (RR=1.3, 95%CI=0.7-2.6) and the lower exposed zone (RR=1.2, 95%CI=0.9-1.6) (Bertazzi *et al*, 2001). The latest report indicates these non-significant excesses remain: the highest exposed zone RR=1.26 (95%CI=0.70-2.29); the lower exposed zone RR=1.11 (95%CI=0.87-1.43) (Consonni *et al*, 2008).

In the occupational setting the literature linking TCDD and lung cancer gives mixed results. A retrospective mortality cohort study of 5172 workers at 12 plants that produced chemicals contaminated with TCDD found a significant excess of respiratory cancers in workers with  $\geq 1$ -year of exposure and  $\geq 20$ -years of latency (SMR=1.42, 95%CI=1.03-1.92) (Fingerhut *et al*, 1991). Further follow-up of the cohort identified a total of 125 lung cancer deaths resulting in a SMR of 1.06 (95%CI=0.88-1.26) with a significant exposure-response relationship with cumulative exposure score (Steenland *et al*, 1999).

A Dutch study of 1129 workers exposed to phenoxy-herbicides, chlorophenols and contaminants (including TCDD), and employed between 1955 and 1985, and followed-up to the end of 1991, found 14 lung cancer deaths (Hooiveld *et al*, 1998). This was among 549 male exposed workers and resulted in a SMR of 1.0 (95%CI=0.6-1.7).

A German study of 2479 workers exposed to phenoxy-herbicides and dioxins at four plants observed a total of 47 lung cancer deaths up to 1992 (Becher *et al*, 1996). This resulted in an overall SMR of 1.43 (95%CI=1.05-1.90), with increases in all time periods since first exposure (<10: SMR=1.80, 95%CI=0.78-3.55; 10-<20: SMR=3.64, 95%CI=0.44-13.14; 20+: SMR=4.25, 95%CI=1.15-10.88).

A New Zealand study of phenoxy herbicide production workers (n=1025) and sprayers (n=703) followed-up from 1969 to 2000 resulted in 12 and five deaths, respectively (Mannetje *et al*, 2005). The SMRs were 1.37 (95%CI=0.71-2.39) and 0.45 (95%CI=0.15-1.05), respectively.

In an IARC historical cohort study of 21863 workers in 36 cohorts from 12 countries, subjects were followed from 1939 to 1992 (Kogevinas *et al*, 1997). A total of 225 lung cancer deaths were observed in workers exposed to TCDD or higher chlorinated dioxins (SMR=1.12, 95%CI=0.98-1.28), compared to 148 with no exposure (SMR=1.03, 95%CI=0.87-1.21) and 380 in all workers exposed to any phenoxy-herbicide or chlorophenol (SMR=1.09, 95%CI=0.98-1.20). The risk of lung cancer showed no pattern with years since first exposure, year of first exposure, or duration of exposure. Measurements of serum TCDD in a number of studies indicated production workers had higher levels than sprayers, and substantially higher levels than the general population. Workers involved in production had a higher lung cancer risk (SMR=1.20, 95%CI=0.97-1.47) compared to sprayers (SMR=1.03, 95%CI=0.78-1.34).

Jones *et al*. (2009) have carried out a systematic review and meta-analysis in 32 studies of crop protection production manufacturing workers. The study included the IARC cohort of Kogevinas, plus a number of others from Europe, USA and China. The summary risk estimate for lung cancer was 1.22 (95%CI=1.05-1.41). In a sub-group of 20 cohorts of workers involved in the manufacture of phenoxy-herbicides the summary risk estimate was 1.28 (95%CI=1.08-1.52).



Bodner *et al.* (2003) investigated the long term mortality of a cohort of 2187 male chemical production workers previously exposed to substantial levels of dioxin. The cohort was followed-up between 1940 and 1994 and there were 54 lung cancer deaths observed (SMR=0.8, 95%CI=0.6-1.1). All exposure to dioxins occurred before 1983. No exposure-response relationship was observed, the greater risk being seen in those with low exposures.

Studies of cancer risk in the pulp and paper industry have reported no overall increase in cancer (Langseth and Andersen, 2000, McLean *et al.*, 2006, Rix *et al.*, 1998). In a cohort of 23,718 male workers employed continuously for at least one year between 1920 and 1993 in Norway there was a significant excess in lung cancer mortality (<3 years: SMR=1.5, 95%CI=1.13-2.03; >=3 years: SMR=1.2, 95%CI=1.09-1.34) (Langseth and Andersen, 2000). A study of a cohort of 20,953 men and 4415 women who worked in Danish paper mills between 1943 and 1990 and followed up to 1993 found a SIR of 1.03 (95%CI=0.88-1.20) among men and 1.42 (95%CI=0.96-2.01) among women (based on 165 and 31 cases, respectively) (Rix *et al.*, 1998). An international collaborative study of workers employed between 1920 and 1996 in 11 countries consisted of 60468 workers (including the above two studies) (McLean *et al.*, 2006). The study found 613 deaths among workers ever exposed to volatile organochlorines (SMR=1.04, 95%CI=0.96-1.13), and 125 deaths among those with high exposure (SMR=1.06, 95%CI=0.88-1.26). Among those exposed to non-volatile organochlorine compounds 314 deaths were observed (SMR=1.04, 95%CI=0.93-1.17). Weighted cumulative exposure to volatile organochlorines did not show a linear trend with NHL risk.

### **2.2.25 Vinyl chloride**

Vinyl chloride (VC) is used almost exclusively by the plastics industry to produce polyvinyl chloride (PVC) and copolymers. It is estimated that only 4,300 workers are exposed to VC in GB mostly in the manufacture of industrial chemicals and other chemical products and plastic products. In 1974 the OEL was set at 12ppm (8-h TWA), which was reduced to 10ppm in 1975. This was further reduced to a MEL of 7ppm in 1989 and then to 3ppm in 2002.

In the assessment of lung cancer risk in workers exposed to vinyl chloride there have been two major multi-centre studies. In a North American study of 10,109 workers, Mundt *et al.* (2000) found no evidence of an association; the SMR was 0.82 (95%CI=0.73-0.92) based on 303 deaths. In a European study of 12,700 workers, 272 deaths were observed, resulting in an SMR of 0.95 (95%CI=0.84-1.07) (Ward *et al.*, 2001). No association was observed between mortality and exposure as estimated by ranked level of exposure, latency, duration of employment and cumulative exposure. Bosetti *et al.* (2003) combined these data to obtain an SMR of 0.88 (95%CI=0.81-0.95).

In addition, in 2003 Boffetta *et al.* (2003) carried out a meta-analysis of five studies and obtained a meta-SMR of 0.90 (95%CI=0.77-1.00).

## **2.3 OCCUPATIONS**

### **2.3.1 Boot and Shoe Manufacturing and Repair**

IARC have classified boot and shoe manufacturing and repair as a Group 1 carcinogenic risk (IARC, 1987). Exposures can include many substances including, leather dust, silicones and waxes, vinyl chloride monomer, isocyanates, benzene and other solvents.

Fu *et al.* (1996) examined cancer risk among shoe manufacturers in England (n=4,215) and Italy (n=2008). The cohorts were followed up from 1939 to 1991. There were a total of 3,647 deaths (England: 3,314; Italy: 333) of which 210 were from lung cancer, 186 in England and 24 in Italy. The respective SMRs for the two countries were 0.60 (95%CI=0.51-0.69) and 1.01 (95%CI=0.65-1.50).

In a case-control study in Germany, Jockel *et al.* (2000) identified 4,184 incident hospital-based lung cancer cases and 4,253 matched population controls between 1988 and 1993. A total of 76 cases and

42 controls were ever employed in the manufacture and repair of shoes, giving an OR of 1.89 (95%CI=1.29-2.78). This was reduced to 1.74 (95%CI=1.12-2.69) after adjustment for smoking and asbestos exposure. The adjusted OR was observed to be more than double after three years of employment.

However, there has been no conclusive evidence suggesting an excess risk of lung cancer.

### **2.3.2 Hairdressers and Barbers**

IARC (1993a) evaluated occupation as a hairdresser or barber as entailing exposures that are probably carcinogenic, but that the increases observed in most studies could be explained by the high rate of smoking within the industry. The various UK occupational health decennial supplements have shown variable risk among hairdressers and barbers. The 1958 decennial supplement for 1949-1953 showed an excess amongst male hairdressers and barbers (PMR=1.15, 95%CI=0.95-1.38) but not for females. However, the 1959-1963 and 1970-1972 supplements showed no excesses. In the 1979-1980/1982-1983 supplements an excess was again seen among males (PMR=2.6, 95%CI=1.65-4.06). However, in the most recent published reports no excesses were again observed (Drever, 1995; Coggon *et al.*, 2009).

In the UK, Alderson (1980) followed a sample of 1,831 male hairdressers identified at the 1961 England and Wales census until 1978, observed 52 lung cancer deaths, but the SMR was only 1.02 (95%CI=0.76-1.34). In other cohort studies reviewed as part of the IARC (1993a) evaluation risks ranged from 1.21-1.9.

In Finland a cohort of 3,637 female and 168 male hairdressers were followed up between 1970 and 1987 (Pukkala *et al.*, 1992). There were 13 incident lung cancers among females, which resulted in an SIR of 1.72 (95%CI=0.92-2.94) when compared to the national population. There were seven lung cancer cases among men which was not significantly different from that expected. Summarising the observed and expected numbers of lung cancers for women and men brought the SIR close to significance (1.59, 95%CI=0.97-2.45).

In the US, Lamba *et al.* (2001) evaluated cancer patterns between 1984 and 1995 among hairdressers and barbers, according to occupation coded on 7.2 million death certificates. Of the 38,721 deaths within the occupation there were 1,701 lung cancer deaths, the majority (1,413) in white women. The OR in this group was 1.32 (95%CI=1.25-1.40), whereas in black women it was 1.26 (95%CI=1.07-1.47; n=162). No excess was observed among male hairdressers. There were 805 deaths among male barbers but no excess MOR was observed among whites or blacks.

In a Swedish study 38,866 female and 6,824 male hairdressers were identified at the 1960, 1970, 1980 and 1990 censuses (Czene *et al.*, 2003). The cohort was followed to 1998. There were 141 incident lung cancers among males, which resulted in an SIR of 1.38 (95%CI=1.16-1.63). The majority of these cases were among those first identified in the 1960 census (n=133), giving an SIR of 1.41 (95%CI=1.18-1.68). For female hairdressers there were 160 incident cases giving an SIR of 1.35 (95%CI=1.15-1.58). Among those identified in the 1960 census there were 109 cases (SIR=1.22, 95%CI=1.00-1.47).

### **2.3.3 Hematite mining (underground) with exposure to radon**

Underground hematite mining with exposure to radon is carcinogenic to humans (IARC, 1987). However, the risk in the UK has decreased with the decline in the industry (Boyd and Doll, 1970, Boyd *et al.*, 1970, Kinlen and Willows, 1988).

Early studies in GB highlighted the increased risk of lung cancer among hematite (iron ore) miners. Boyd *et al.* (1970, 1970) studied the mortality of Cumberland iron ore miners by examining the death certificates of 5,811 men who died between 1948 and 1967 in two local authority areas. During the

follow-up period there were 42 deaths from lung cancer among iron mine employees, 36 of which occurred in miners working underground. This resulted in an SMR of 1.75 (95%CI=1.22-2.42) when compared to local rates and 1.67 (95%CI=1.17-2.32) when compared to the national rates.

In another study of 1,947 Cumbrian miners studied over 1939 to 1982 -84 lung cancer deaths were found (SMR=0.97, 95%CI=0.77-1.20) (Kinlen and Willows, 1988). A non-significant increased risk was observed in miners who worked underground (SMR=1.21, 95%CI=0.86-1.66), but not in those who worked above ground or others when compared to the national population. When compared to local rates the SMR was significantly increased (SMR=1.53, 95%CI=1.009-2.09).

### 2.3.4 Iron and Steel Founding

The iron and steel foundry industry has been classified by IARC as implying a carcinogenic risk (IARC, 1987). Exposure in the industry is to a variety of substances, including silica, cobalt, airborne PAHs, chromium and nickel, phenol, formaldehyde, isocyanates and various amines. Cohort studies have identified relative risks ranging from 1.5 to 2.5 (IARC, 1984c, IARC, 1987), PMR studies show risks ranging from 1.5 to 1.8, while higher risks were observed in some case-control studies. PAHs and silica have been suggested as the main exposures associated with an increased risk in iron foundries, whilst PAHs, silica, chromium and nickel are implicated in steel foundries (Austin *et al*, 1997). In 1997 MELs for foundry particulate were set at 10mg/m<sup>3</sup> (8-h TWA) for total inhalable particulate and 4mg/m<sup>3</sup> for respirable particulate. In 2005 the MEL was redefined as a WEL. From data made available to the HSE by industry it is estimated that there were a total of 540 foundries employing 31,500 workers in 2004 (HSE, personal communication).

Mortality among a cohort of UK steel foundry workers was studied between 1946 and 1990 (Sorahan *et al*, 1994). The vital status of 1,438 men employed between 1946 and 1965 for at least one year was investigated. There was a total of 3,976 deaths giving a significant increase in mortality (SMR=1.15, 95%CI=1.12-1.19). There were 551 lung cancer deaths, which also resulted in a significant excess mortality (SMR=1.46, 95%CI=1.34-1.58). Excesses were seen in all areas of the industry and a number of occupations within these areas:

Industry area/Occupation	N	SMR	95%CI
All foundry areas:	246	1.52	1.33-1.72
Furnace	37	1.77	1.25-2.44
Centrifugal casting	10	2.32	1.12-4.28
Labourers, etc.	100	1.68	1.37-2.04
All fettling shops:	136	1.69	1.42-2.00
Fettling	63	1.81	1.39-2.32
Burning and welding	19	1.69	1.01-2.63
Labourers, etc.	33	1.85	1.27-2.59
All pattern/machine/maintenance/inspection:	169	1.24	1.06-1.45
Machine shop labourers	35	1.47	1.02-2.04
Maintenance mates	26	1.71	1.12-2.51

Mortality remained in excess irrespective of the year of entry into the cohort or years from first employment, the highest being in 1956-1960 and 10-19 years, respectively. The trend in RRs by employment duration in the industry, foundry area and fettling shop approached significance. When employment in foundry area and fettling shop were combined the trend was significant.

Duration of employment	RR	95%CI
None	1.0	
>0.0	1.21	0.98-1.51
5.0-	1.44	1.13-1.82
≥15.0	1.26	0.95-1.67
Trend	1.11	1.02-1.21

The excesses were said not to be due to smoking.

Among German foundry workers excesses of lung cancer risk have also been observed (Adzersen *et al*, 2003). In a cohort of 17,708 male production workers first employed in 1950-1985 with at least one year of employment, mortality was followed to 1993. There were 3,972 deaths in total giving an SMR of 1.154 (95%CI=1.119-1.191). There were 322 observed lung cancer deaths. However, more than 1000 death certificates were unavailable, so the authors calculated what the expected observed number should have been based on the distribution within the numbers that were available. Thus, using this they stated 415 was the estimated observed number of cases. Comparing this with national rates resulted in an SMR of 1.64 (95%CI=1.24-2.23). In the cohort after 1980 the SMR was reduced slightly to 1.517 (95%CI=1.344-1.707). Mortality decreased slightly with duration of exposure but was only significant with <10 years exposure (SMR=1.73, 95%CI=1.14-2.73). Mortality, however, increased with duration of observation (time since first employment), being statistically significant after 10years of observation.

In a Danish cohort of 3,056 foundry workers the mortality experience was compared with 43,024 workers employed in other industries (Hansen, 1997). Mortality was followed up between 1970 and 1992, and there were 886 deaths among workers and 12,795 among control workers. Among workers there were 84 respiratory cancer deaths, with an SMR of 1.01 (95%CI=0.80-1.25).

In a Norwegian population-based case-control study Grimsrud *et al*. (1998) identified 86 lung cancer cases and 196 controls between 1980 and 1992 in a municipality with iron and steel producing industry. An increased OR of 2.9 (95%CI=1.2-6.7) was associated with exposure to PAHs, and also with work experience in the pig iron department (OR=2.8, 95%CI=1.1-7.0) after adjustment for smoking. However, in most cases the excess risk was associated with exposure to asbestos and/or PAHs.

Among iron foundry workers and engine manufacturing plants a nested case-control study of 231 cases (408 controls) was undertaken (Austin *et al*, 1997). However, there was no association with usual plant of employment and lung cancer mortality. In addition, there was no trend with duration of employment in the foundry. However, the OR for working in quality control was significantly increased at 5.5 (95%CI=1.1-27), which increased to 6.3 (95%CI=0.71-56.0) after adjustment for smoking. The OR was not increased in any other group of workers.

Rodriguez *et al*. (2000) carried out a nested case-control study of 144 male cases and 558 controls selected from 24,400 workers employed in the Spanish iron and steel foundry industry. The workers had been employed between 1952 and 1995. Workers ever employed in the blast furnace had an excess lung cancer risk (OR=2.55, 95%CI=1.25-5.21) after adjusting for smoking. Similar excess was observed for workers having their longest job employment in the blast furnace. An almost two-fold risk was also seen in employees in the foundry.

### 2.3.5 Production of art glass, glass containers and pressed ware

IARC (1993b) have concluded that there is limited evidence that occupational exposures in the manufacture of art glass, glass containers and pressed glassware are carcinogenic. This evaluation was based on the consistent results, in different studies, regarding the risk of lung cancer (Pirastu *et al*, 1998, Wingren and Englander, 1990, Wingren and Axelson, 1993, Wingren, 2004). Cordioli *et al*.

(1987) followed 468 Italian male glass workers employed between 1953 and 1967 to 1985. The RR for lung cancer was 2.09 (95%CI=1.1-3.6) based on 13 cases. Neuberger and Kundi (1990) recruited 1,626 men employed during 1950-1960 and followed them to 1985. There were 179 lung cancer deaths in the exposed cohort, of which 28 were among subjects with the occupational title 'ceramics and glass', who had a RR of 2.37 (95%CI=1.58-3.43).

Wingren and Englander (1990) investigated a Swedish cohort of 625 male art glass workers employed between 1964 and 1985. Based on six lung cancer deaths mortality was in slight excess (RR=2.4, 95%CI=0.9-5.2). In an update to this study, 1,229 men and women employed during the period 1964-1987 were followed to 1997 (Wingren, 2004). However, no new lung cancer deaths were observed giving an SMR of 0.84 (95%CI=0.3-1.8). No increase was observed in lung cancer incidence, among men, although an excess was seen among women (SIR=2.13, 95%CI=0.26-7.70) based on two cases.

In a Finnish cancer incidence study, 1,803 men and 1,946 women were followed from 1953 to 1986 (Sankila *et al*, 1990). A small excess lung cancer risk was observed overall (SIR=1.28, 95%CI=0.99-1.62), and for automated glass blowers (SIR=1.60), but not among oral glass-blowers (SIR=0.29).

Also in Sweden in a population-based case-control study by Wingren and Axelson (1985) and excess of lung cancer was found in unspecified glass-workers with an OR of 2.4 (95%CI=1.0-5.8), based on seven exposed cases. An update of this study by the same authors estimated an OR of 1.7 (95%CI=1.0-2.8) for all glass workers, 2.3 (95%CI=0.8-6.3) for glass blowers and 1.9 (95%CI=1.0-3.7) for unspecified workers (Wingren and Axelson, 1987). A later study attempted to identify certain exposures as determinants of the cancer risks; however, for lung cancer no obvious trend with exposure to any metal could be found (Wingren and Axelson, 1993).

A study in Italy of 3,390 (3,180 men; 210 women) art glass workers followed between mid-1950s to 1993 (Pirastu *et al*, 1998) found and SMR for lung cancer of 1.23 (95%CI=1.00-1.51).

### **2.3.6 Isopropyl alcohol manufacture (strong acid process)**

The manufacture of isopropyl alcohol by the strong acid process is classified by IARC as a Group 1 carcinogen (IARC, 1987), although a review evaluated the evidence for an increased risk of lung cancer was only suggestive (Siemiatycki *et al*, 2004).

In a US study of chemical plant employees 1,031 alcohol process workers were followed from the early 1940s to 1983 (Teta *et al*, 1992). However, no excess lung cancer risk was observed among workers involved in the production of alcohol by the strong acid process, which was explained as due to the initiation of engineering controls and health monitoring that took place after the original medical observations of a previous study.

In a study of 262 UK male workers on an isopropyl alcohol plant at an oil refinery followed up to 1975 there were only two lung cancer deaths giving an SMR of 0.78 (95%CI=0.09-2.81) (Alderson and Rattan, 1980).

### **2.3.7 Painters**

Many chemicals are used in paint products such as pigments, extenders, binders, solvents and additives. Painters are commonly exposed by inhalation to solvents and other volatile paint components; inhalation of less volatile and non-volatile compounds is common during spray painting (IARC, 1989). Titanium dioxide and chromium and iron compounds are used widely as paint pigments. IARC have classified occupational exposure as a painter as Group 1. Studies of painters consistently show an excess of lung cancer of about 40% (IARC, 1989) and the evidence indicates that the excess cannot be explained by smoking alone.

Matanoski *et al.* (1986) conducted a cohort mortality study of the membership of a large international union of painters and allied tradesmen. The experience of 57,175 current and former union members in four US states were followed from 1975 to 1979. There were 448 lung cancer deaths, resulting in an SMR of 1.06 (95%CI=0.96-1.16), and a PMR of 1.14 (95%CI=1.05-1.25). For members of local trade affiliations comprising mainly painters, the SMR was significantly increased at 1.18 (95%CI=1.06-1.32).

In another US study of members of the painters union, the cohort consisted of 42,170 painters and 14,316 non-painters, who were born before 1940 and alive at the end of 1975; follow-up was to 1994 (Steenland and Palu, 1999). Among painters there were 18,259 deaths compared to 4,247 among non-painters. There were 1,746 lung cancer deaths among painters giving an SMR of 1.23 (95%CI=1.17-1.29), whereas there were 422 among non-painters resulting in an SMR of 1.02 (95%CI=0.92-1.12). SMRs 20-years since first union membership were 1.24 (95%CI=1.18-1.31) and 0.96 (95%CI=0.85-1.08), respectively. Poisson regression models comparing painters with non-painters indicated the former had a significantly increased risk of lung cancer (rate ratio=1.23, 95%CI=1.11-1.35).

Chen and Seaton (1998) carried out a meta-analysis of studies of workers exposed to paints and referring to painters and published between 1966 and 1995. A total of 58 papers were identified. For lung cancer the combined SMR was 1.29 (95%CI=1.19-1.40). In studies among painters from occupational cohort studies the combined SMR was 1.21 (95%CI=1.12-1.31). However, the confounding effects of smoking and alcohol could not be entirely excluded.

### **2.3.8 Non-arsenical insecticides (occupational exposure in spraying and application)**

Occupational exposures in the spraying and application of non-arsenical insecticides have been classified by IARC as a Group 2A carcinogenic risk (IARC, 1991). Insecticides are applied by aerial spraying and by various ground-based techniques, ranging from hand-held sprayers and dusters to vehicle-mounted hydraulic sprayers, air sprayers, foggers and power dusters. Occupational exposures occur in the mixing and loading of equipment and in the spraying and application of insecticides. Absorption resulting from dermal exposure is the most important route of uptake for exposed workers, but inhalation may also occur if respiratory protective equipment is not used. Lung cancer has been causally linked with exposure to arsenical compounds (IARC, 1987) and an excess risk was observed among vineyard workers (Luchtrath, 1983) and pesticide manufacturers (Mabuchi *et al.*, 1979, Mabuchi *et al.*, 1980); these substances were taken off the market many years ago.

Studies of pesticide applicators have shown variable results. In a cohort of 33,658 licensed applicators in Florida, USA, vital status was followed to 1993 (Fleming *et al.*, 1999). Among men and women there were 180 and 9 lung cancer death, respectively, giving SMRs of 0.89 (95%CI=0.76-1.03) and 0.49 (95%CI=0.22-0.93). Among men lung cancer risk was lower among private applicators (SMR=0.86, 95%CI=0.73-1.01) than commercial and public applicators (SMR=1.04, 95%CI=0.72-1.46). In another US study of a cohort of 9,961 male aerial applicators, mortality was followed to 1988 (Cantor and Silberman, 1999). Mortality rates were compared to a similar sized control group of flight instructors. Among the applicators there were 79 lung cancer deaths (49/100,000) compared to 79 among instructors (49.1/100,000), with a rate ratio of 1.0 (95%CI=0.8-1.3). The SMRs for both groups were significantly reduced at 0.67. Swaen *et al.* (2004b) followed a cohort of 1,341 Dutch applicators to 2001. There were 27 cancers of the trachea/lung observed resulting in an SMR of 0.71 (95%CI=0.47-1.04).

Burns (2005) carried out a review of cancer risk among pesticide manufacturers and applicators. Very few of the studies reviewed had an SMR lung cancer risk above 1.0, and if the risk was greater than 1.0 it was non-significant.

The US Agricultural Health Study (AHS) is a large prospective cohort study of private and commercial applicators, and spouses of farmer applicators. The participants were from the states of Iowa and North Carolina, and consisted of 52,395 private and 4,916 commercial applicators, and

32,347 spouses (total=89,658). For cancer incidence, enrolment was up to 2002, during which time 266 lung cancer deaths were observed among private applicators and 12 among commercial ones (Alavanja *et al*, 2005). This resulted in respective SMRs of 0.47 (95%CI=0.41-0.53) and 0.59 (95%CI=0.30-1.03). Among spouses the SMR was 0.41. For deaths, mortality was assessed to 2000. Among private applicators there were 129 lung cancer deaths (SMR=0.4, 95%CI=0.3-0.4). However, although overall risk was reduced, due in large part to a low cigarette smoking prevalence, exposure-response relationships were found with a number of widely used herbicides and insecticides (Alavanja *et al*, 2004). Table 19 below shows some evidence of exposure-response for lung cancer. Nevertheless, the authors could not rule out the possibility of chance because of multiple testing.

**Table 19** Lung cancer risk among applicators in the US Agricultural Health Study for different pesticide exposures (source: Alavanja *et al.*, 2004)

Pesticide by lifetime exposure days	No. of exposed cases	OR (95%CI)
Dicamba		
<24.5	21	1.0
24.5-108.5	19	1.3 (0.7-2.5)
108.6-224.7	8	1.7 (0.7-4.0)
>224.7	8	3.1(1.2-7.7)
Metolachlor		
<38.8	20	1.0
38.8-116	20	1.6 (0.8-3.0)
116.1-457.0	8	1.2 (0.5-2.9)
>457.0	6	5.0 (1.7-14.9)
Pendimethalin		
<20.0	12	1.0
20.1-56.0	10	1.6 (0.7-3.9)
56.1-224.7	6	2.1 (0.8-6.0)
>224.7	4	4.4 (1.2-15.4)
Carbofuran		
<24.5	21	1.0
24.6-108.5	11	1.4 (0.7-3.1)
>108.5	11	2.3 (1.0-5.1)
Chlorpyrifos		
<24.5	33	1.0
24.5-103.0	13	1.1 (0.6-2.1)
103.1-116.0	12	1.7 (0.9-3.4)
>116.0	11	1.9 (0.9-4.0)
Diazinon		
<20.0	10	1.0
20.1-108.5	11	1.6 (0.7-3.9)
>108.5	7	3.2 (1.1-8.9)

A more detailed analysis of carbofuran exposure within the AHS cohort found that the RRs for lung cancer showed a significant trend with days of use per year and years of use, but not intensity-weighted lifetime-exposure days (Bonner *et al*, 2005). The RRs were adjusted for numerous factors including smoking and exposure to other pesticides. Similar findings were observed for exposure to diazinon (Beane-Freeman *et al*, 2005), metolachlor (Rusiecki *et al*, 2006) and dicamba (Samanic *et al*, 2006). For pendimethalin the trends for lung cancer risk were inconsistent for different exposure metrics, although an excess occurred in the highest exposure category for lifetime exposure (Hou *et al*, 2006). For chlorpyrifos-exposed workers an excess overall lung cancer risk has been observed (RR=1.36, 95%CI=0.96-1.93), and significant trends were observed with lifetime and intensity-weighted exposure (Lee *et al*, 2004). However, mortality was not increased (Lee *et al*, 2007).

Farmers are a large occupational group that are exposed to pesticides and many studies have investigated cancer risk among them. In a meta-analysis of 37 studies, 29 were used to assess an

overall lung cancer risk (Acquavella *et al*, 1998). From these the pooled RR was 0.65 (95%CI=0.58-0.73).

A systematic review and meta-analysis of mortality in crop protection product manufacturing workers reviewed 21 references that reported information on 37 separate cohorts (Jones *et al*, 2009). For lung cancer 36 studies reported mortality and the pooled estimate was 1.26 (95%CI=1.093-1.45) but there was significant heterogeneity between the studies. For 20 studies that considered phenoxy-herbicide exposure the pooled estimate increased to 1.34 (95%CI=1.128-1.596) and there was no heterogeneity.

In a specific analysis of workers exposed to phenoxy-herbicides, chlorophenols and dioxins, Kogevinas and colleagues (1997) assembled a cohort of 21,863 male and female employees in 12 countries. Subjects were followed from 1939 to 1992. Among workers exposed to TCDD and higher chlorinated dioxins there were 225 lung cancer deaths giving an SMR of 1.12 (95%CI=0.98-1.28), compared to 148 among workers not exposed who had an SMR of 1.03 (95%CI=0.87-1.21). Among all workers exposed to any phenoxy-herbicide or chlorophenol there were 380 deaths giving an SMR of 1.09 (95%CI=0.98-1.20). However, no relationship was observed between risk and duration of exposure.

In a study from New Zealand of 1,025 phenoxy-herbicide producers and 703 sprayers through 2000 a total of 17 lung cancer deaths were observed (Mannetje *et al*, 2005). The SMR for production workers was slightly increased at 1.37 (95%CI=0.71-2.39), whereas for sprayers it was reduced at 0.45 (95%CI=0.15-1.05).

### **2.3.9 Rubber industry**

Employment in the rubber industry is classified by IARC as a Group 1 carcinogenic risk (IARC, 1982, IARC, 1987). Working in the industry gives rise to possible exposure to rubber processes, dusts and fumes that may lead to workers being exposed to many chemicals, including PAHs, Cr VI compounds, lead and lead compounds, crystalline silica, cadmium and cadmium compounds, cobalt and cobalt compounds, acrylonitrile, styrene, 1,3-butadiene and n-nitrosodimethylamine. In 1994 a GB MEL for rubber fume (RF) was set at 0.6mg/m<sup>3</sup> (8-h TWA) and for rubber process dust (RPD) at 6mg/m<sup>3</sup> (8-h TWA). In 2005 the MEL was converted to a WEL.

In GB numerous papers have been published on the mortality and cancer incidence within the country's rubber industry. Sorahan *et al*. (2000) investigated mortality (1955-1996) and cancer incidence (1971-1992) of a cohort of 2,610 male workers from a factory manufacturing chemicals for the rubber industry. There were 102 deaths from cancer of the lung and trachea, compared to 117.4 expected giving a reduced SMR of 0.87 (95%CI=0.71-1.05). There were 65 incident cases, with 744 expected, resulting in a SIR of 0.87 (95%CI=0.67-1.11).

Sorahan *et al* (1989) investigated the British rubber industry and examined mortality of 36,691 workers during the period 1946-1985. All workers had been employed in 1946-1960 at one of 13 factories for at least one year. There were 11,765 deaths during this period, of which 1,592 were from lung cancer. However, 1,219 were expected, resulting in an SMR of 1.31 (95%CI=1.24-1.37). There did not appear to be any pattern by the year of first employment.

In a second study in the industry, 9,031 employees of 42 UK factories with at least one year employment and first employed between 1982 and 1991, were followed to 1998 (Straughan and Sorahan, 2000). There were 11 (12.7 expected) lung cancer deaths, giving an SMR of 0.87 (95%CI=0.43-1.55), and six (8.01 expected) registrations (SRR=0.75, 95%CI=0.28-1.63) among men. No lung cancer deaths were seen among women. A more recent follow-up of the cohort to 2004 observed 22 male and two female lung cancer deaths, giving respective SMRs of 0.93 (95%CI=0.58-1.40) and 0.70 (95%CI=0.08-2.53) (Dost *et al*, 2007). There were 27 male registrations resulting in an SRR of 0.98 (95%CI=0.64-1.43). Increased SMRs reported for historical cohorts of UK rubber workers may therefore not be apparent in more recent follow-up periods.



A study of a similar cohort of American workers investigated mortality among 1,749 workers between 1946 and 1988 (Prince *et al*, 2000). There were 13 lung cancer deaths in the whole cohort: seven definitely exposed, three possibly exposed, three probably not exposed. The respective SMRs were 1.4 (95%CI=0.5-2.8), 0.6 (95%CI=0.1-1.7), and 0.4 (95%CI=0.1-1.3).

These results contrast to those of the German rubber industry (Weiland *et al*, 1998). In a cohort of 11,633 male workers mortality was investigated from 1981 to 1991. There were 257 lung cancer deaths resulting in an SMR of 1.30 (95%CI=1.15-1.47). After stratification by work area, significantly increased risks were observed in the preparation of materials, technical rubber goods and maintenance, and increases of borderline significance in the tyres work area. Stratification by year of hire or by years of employment in the preparation of materials showed increased risks among workers employed before 1960. In contrast, workers in technical rubber goods and maintenance a greater risk was seen in those hired after 1960.

In 1998, IARC sponsored a review of the evidence for cancer risk in the rubber industry (Kogevinas *et al*, 1998). The study reviewed 12 cohort studies, seven industry-based nested case-control studies, 48 community-based case-control studies and 23 studies based administration data. The studies were mainly from Europe and USA/Canada, with five from China, one from Russia and one from South America. In the cohort studies excess risks (ranging from 1.7 to 3.3) were seen in only four studies, whereas in case-control studies risks ranging from 1.5 to 4.6 were seen in five studies.

In another UK study of workers at a large tyre factory, Veys (2004) studied three quinquennial intakes between 1946 and 1960. A total of 6,454 men were followed-up between 1946 and 1985. There were 2,658 deaths of which 329 were from lung cancer. Compared to national rates this resulted in an SMR of 1.20 (95%CI=1.08-1.34) whereas when compared to local rates it was 0.94 (95%CI=0.84-1.05).

Alder *et al*. (2006) carried out a systematic review and meta-analysis of cohort studies published to 2003. For lung cancer mortality 24 studies were identified and a pooled risk estimate of 1.05 (95%CI=0.94-1.18) was obtained, although there was significant heterogeneity between studies. For incidence, five studies were combined to give a pooled estimate of 1.12 (95%CI=0.92-1.36) but this time there was no heterogeneity. In cohorts of workers exclusively producing tyres the pooled estimate was 0.95 (95%CI=0.78-1.15).

In a recent update of 17,924 North American synthetic rubber industry workers, included in the meta-analysis, mortality was examined between 1943 and 1998 (Sathiakumar *et al*, 2005). There were 563 lung cancer deaths giving an overall SMR of 0.91 (95%CI=0.84-0.99).

### **2.3.10 Welders**

Welders are exposed to a variety of fumes and gases. Fume particles contain a mixture of oxides and salts of metals and other compounds. Fumes from welding stainless steel and other alloys contain nickel compounds and chromium VI and III. Other exposures include ozone, oxides of nitrogen, PAHs, and welders in shipyards may also be exposed to asbestos dust. Welders also tend to smoke more than the general population.

Moulin (1997) carried out a meta-analysis on lung cancer risk among shipyard, mild steel and stainless steel welders. A total of 18 case-control and 31 cohort studies were included in the analysis. The combined RR values were 1.38 (95%CI=1.29-1.48) for “all or unspecified welding categories”, 1.30 (95%CI=1.14-1.48) for shipyard welders, and 1.35 (95%CI=1.15-1.58) for non-shipyard welders. Similar combined RR values were observed for mild steel welders (1.50, 95%CI=1.18-1.91) and stainless steel welders (1.50, 95%CI=1.10-2.05).

Ambroise *et al*. (2006) updated the above meta-analysis to cover the period 1954 to 2004. A total of 60 studies were included in the analysis mostly from the US (n=26) and Europe (n=26). The combined

RR for both the fixed- and random-effects models were the same (CRR=1.26, 95%CI=1.20-1.32). There were no significant differences between the types of welding:

	<b>RR</b>	<b>95%CI</b>
Unspecified	1.24	1.18-1.31
Shipyards	1.32	1.16-1.51
Mild steel	1.32	1.10-1.59
Stainless steel	1.31	1.06-1.61

### 2.3.11 Wood industry

Wood dust is generated during the processing of wood for a wide range of uses and exposure is a potential risk factor for lung cancer development (Barcenas *et al*, 2005). The MEL for both hardwood and softwood is 5mg/m<sup>3</sup> (8-h TWA). Wood dust has been designated as a human carcinogen based on increased sinus and nasal cancer rates among exposed workers (IARC, 1995). However, data on an association with lung cancer has been inconclusive, mainly because of small sample sizes, inadequacy of the control groups and lack of control of confounding factors such as smoking.

In a case-control study of 1,368 lung cancer cases, self-reported wood dust exposure was compared with that of 1,192 cancer-free controls (Barcenas *et al*, 2005). Employment in a wood dust related occupation or industry showed an increased OR for lung cancer (3.15, 95%CI=1.45-6.86). The OR was also significantly increased in individuals self-reporting wood dust exposure (OR=1.54, 95%CI=1.15-2.08) and for an overall summary exposure measure (OR=1.60, 95%CI=1.19-2.14). The OR also increased with years of employment in any occupation/industry. The OR for those who reported exposure to wood dust and also smokers was 2.87 (95%CI=2.01-4.10), whereas for non-smokers the OR was 1.57 (95%CI=0.85-2.87).

In a pooled analysis of data from five cohort studies of wood-related industries, Demers *et al*. (1995) identified 28,704 workers. The industries were a mixture of furniture, plywood and wood model workers. There were a total of 7,665 deaths of which 575 were from lung cancer. However, 721 were expected, giving an SMR of 0.8 (95%CI=0.7-0.9). There was no change in risk with category of wood dust exposure.

### 3 ATTRIBUTABLE FRACTION ESTIMATION

#### 3.1 GENERAL CONSIDERATIONS

##### Substances and Occupations

The substances considered in the estimation of the attributable fraction (AF) for lung cancer are those outlined in Table 20.

**Table 20** Substances considered in the estimation of the attributable fraction for cancer of the lung

Agents, Mixture, Circumstance	AF calculated	Strength of evidence	Comments
<b>Group 1: Carcinogenic to Humans</b>			
<b>Agents, groups of agents</b>			
Arsenic & arsenic compounds	Y	Strong	
Asbestos	Y	Strong	
Beryllium	Y	Strong	
Bis(chloromethyl)ether & chloromethyl methyl ether	N	Strong	Small numbers exposed
Cadmium & cadmium compounds	Y	Strong	
Chromium [VI] compounds	Y	Strong	
Environmental tobacco smoke	Y	Strong	
Ionising radiation	Y	Strong	
Mineral oils	Y	Strong	
Mustard gas	N	Suggestive	Small numbers exposed
Nickel compounds	Y	Strong	
Coal-tar and pitches	N	Suggestive	Included with PAHs
Soots	N	Strong	Included with PAHs
Radon & its decay products	Y	Strong	
Crystalline silica	Y	Strong	
Strong inorganic-acid mists containing sulphuric acid	Y	Suggestive	
Talc containing asbestiform fibres	N	Strong	Included with asbestos
Dioxin (TCDD)	Y	Suggestive	
<b>Exposure circumstances</b>			
Aluminium production	N	Strong	Included with PAHs
Coal gasification	N	Strong	Included with PAHs
Coke production	N	Strong	Included with PAHs
Hematite mining (underground) with exposure to radon	N	Strong	Small numbers exposed
Tin miners	Y	Strong	Cornish tin miners included because of exposure to radon
Iron & steel founding	Y	Strong	
Painter (occupational exposure)	Y	Strong	
<b>Group 2A: Probably Carcinogenic to Humans</b>			
<b>Agents &amp; groups of agents</b>			
$\alpha$ -Chlorinated toluenes & benzoyl chloride (combined exposure)	N	Suggestive	Small numbers exposed
Cobalt	Y	Suggestive	
Diesel engine exhaust	Y	Suggestive	
Epichlorohydrin	N	Suggestive	Unknown number of workers exposed
Inorganic Lead	Y	Suggestive	
Nonarsenical insecticides	N	Suggestive	Included with dioxins
PAHs	Y	Suggestive	AF calculation includes workers

**Table 20** Substances considered in the estimation of the attributable fraction for cancer of the lung

Agents, Mixture, Circumstance	AF calculated	Strength of evidence	Comments
			exposed to coal-tar and pitches, soots, aluminium production, coal gasification, coke production
<b>Exposure circumstances</b>			
Art glass, glass containers, & pressed ware (manufacture)	N	Suggestive	Included with arsenic, asbestos, silica, PAHs
Hairdressers and barbers	N	Suggestive	Included with ETS, or confounded with own smoking
Isopropyl alcohol manufacture, strong acid process	N	Suggestive	Included with strong acids /chromium
Rubber industry	N	Suggestive	British study gives negative risk estimates
<b>Group 2B: Possibly Carcinogenic to Humans</b>			
<b>Exposure circumstances</b>			
Welders (occupational exposure to welding fumes)	Y	Suggestive	

### Data Relevant to the Calculation of AF

The two data elements required are an estimate of relative risk (RR), and either (1) an estimate of the proportion of the population exposed (Pr(E)) from independent data for Great Britain, or (2) an estimate of the proportion of cases exposed (Pr(E|D)) from population based study data.

The RR chosen from a 'best study' source is described for each exposure, with justification of its suitability. Information on the 'best study' and independent data sources for the proportion of the population exposed are also summarised for each exposure in the appropriate section below. In the absence of more precise knowledge of cancer latency, for solid tumours a latency of up to 50 years and at least 10 years has been assumed for all types of the cancer. Therefore it is assumed that exposure at any time between 1956 and 1995 (the Risk Exposure Period, REP) can result in a cancer being recorded in 2004 as a registration or in 2005 as an underlying cause of death. Although strictly speaking the REP for cancer registrations recorded in 2004, the year for which estimation has been carried out, would be 1955-1994, for simplification the years 1956 to 1995 have also been used, as for deaths, as the proportion exposed will not be affected. For an independent estimate of the proportion of the population exposed, numbers of workers ever exposed during this period are estimated by extrapolating from a point estimate of exposed workers taken from the period. If this is from CAREX relating to 1990-93, an adjustment is made to take account of gross changes in employment levels which have occurred particularly in manufacturing industry and the service sector across the REP. Otherwise a point estimate that represents numbers employed as close as possible to about 35 years before the target year of 2005 is used, as this is thought to represent a 'peak' latency for the solid tumours, and is also close to the mid-point of the REP for estimating numbers ever exposed across the period (for which a linear change in employment levels is implicitly assumed). Where the Census of Employment is used, the point estimate data are for 1971. Where the LFS is used, the first year available is 1979. A turnover factor is applied to estimate numbers ever exposed during the REP, determined mainly by the estimate of staff turnover per year during the period. For each exposure therefore, if an AF has been based on independent estimates of numbers exposed, the table of results includes the point estimate of numbers employed, the adjustment factor for CAREX if applicable, the staff turnover estimate, and the resulting estimate of numbers ever exposed during the REP. Other estimates used in the calculations that remain constant across exposures (unless otherwise stated) are given below:

- Number of years in REP = 40
- Proportion in the workplace ever exposed is set to one, i.e. all are assumed to be exposed, in the absence of more detailed information. Where sources other than CAREX are used for the point estimate of numbers exposed, such as the LFS or Census of Employment, a precise as possible definition of workers exposed is sought.
- Numbers ever of working age during the target REP = 19.4 million men, 21.0 million women. This is the denominator for the proportion of the population exposed, and is based on population estimates by age cohort in the target year.
- Total deaths from lung cancer in GB in 2005 = 19,045 for men aged 25+ (16850 England and Wales and 2195 Scotland), 13,753 for women aged 25+ (11,939 England and Wales and 1,814 Scotland).
- Total registrations from lung cancer in GB in 2004 = 21,923 for men aged 25+ (18,101 England, 1,316 Wales and 2,506 Scotland), 15,455 for women aged 25+ (12,353 England, 943 Wales and 2,160 Scotland).

Attributable numbers are estimated by multiplying the AF by the total number of cancers in GB. Only cancers, which could have been initiated during the risk exposure period, are counted, taking normal retirement age into account. Therefore for solid tumour cancers, total deaths or registrations recorded at all adult ages (25+) are used to estimate attributable numbers, and for short latency cancers, deaths and registrations for ages 15-84 for men and 15-79 for women are used.

For each agent where data on worker numbers are only available for men and women combined (CAREX data), the assumed percentage of men is given in addition to the numbers exposed. The allocation to high and low, and occasionally negligible, exposure level categories, or division into separate exposure scenarios, is also included in these tables. Where no separate estimate of relative risk is available for the low exposure level category, an estimate is based on an average of the high/low ratios for cancer-exposure pairs for which data were available.

Full details of the derivation of the above factors and the methods of calculating AF are published separately. Unless otherwise stated, Levin's method is used for estimates using independent estimates of numbers exposed, and Miettinen's method is used for study based estimates. A summary of the methodology is given in the Statistical Appendix.

## 3.2 ARSENIC

### (a) Risk estimate

The ATSDR toxicological profile of arsenic concluded “in general, studies reporting long-term exposure to 0.07mgAs/m<sup>3</sup> or greater have shown an increased incidence of lung cancer, while at low exposure levels, the association has been less clear or not present” (ATSDR, 2005b). Lee-Feldstein (1986) in a study of smelter workers estimated an SMR for low exposed groups (<5 mg/m<sup>3</sup>.months) of 1.74 (95%CI=0.75-3.43), which is used in the present study for the low exposure group. For exposures above this level in this study the SMR was 2.05 (95%CI=1.43-2.85), and this was used for the high exposure group.

It should be noted that, although there has been an update of the Lee Feldstein study by Lubin (2000) by exposure category, results are not given exclusively for lung cancer. In addition, there is some uncertainty about the shape of the dose-response curve (Enterline *et al*, 1987), and care must be taken when interpreting results if exposure estimates are based on airborne or urinary concentrations of arsenic. The dose-response relationship based on airborne concentrations followed a concave downward curve (the response rate increasing but at a reducing rate with rising dose), but when based on urine concentrations it followed a linear relationship.

### (b) Numbers exposed

The CAREX database estimated there were about 25,000 GB (Great Britain) workers exposed to arsenic between 1990 and 1993. The majority of these were employed in the non-ferrous metal basic industry (37.1%) and the manufacture of wood and wood and cork products (25.7%). Table 23 gives the number of workers exposed to arsenic in the UK for 1990-1993, according to the CAREX database. The exposed numbers have been divided between men and women on the assumption that the CAREX exposed numbers were “blue collar” workers<sup>8</sup> in manufacturing industry and electricity, gas and steam and construction at both high and low exposure levels, and were in ‘elementary occupations’ with low exposure in the service industries. It has also been assumed that no women would have been in the ‘high exposed’ group in the manufacturing industry and electricity, gas and steam sectors for arsenic, so these workers have been allocated to the ‘low exposed’ group. Numbers employed in ‘Iron and steel basic industries’ have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers.

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<sup>8</sup> “Blue collar” workers have been defined as those in the skilled trades, shop floor occupations and transport operatives, in Standard Occupational Classification major groups 5, 8 and 9.

**Table 21** Numbers of workers exposed to arsenic according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Manufacture of wood and wood and cork products, except furniture	6435	132975	H
Manufacture of furniture and fixture, except primary of metal	1523	144325	H
Manufacture of industrial chemicals	805	130000	L
Manufacture of other chemical products	50	175175	L
Petroleum refineries	44	18075	L
Manufacture of glass and glass products	1284	43275	H
Manufacture of other non-metallic mineral products	222	70875	L
Iron and steel basic industries	325	48425	L
Non-ferrous metal basic industries	9277	79325	H
Manufacture of electrical machinery, apparatus, appliances and supplies	1450	473750	L
Manufacture of transport equipment	21	456900	L
Other manufacturing industries	53	59375	L
Electricity, gas and steam	304	140975	L
Construction	2820	1753450	H
Sanitary and similar services	370	274225	L
Recreational and cultural services	37	534600	L
<b>Total</b>	<b>25020</b>	<b>4,535,725</b>	
<b>Main Industry Sector</b>		% Male	
Agriculture, hunting and forestry; fishing	High Low	0 0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High Low	14074 7394	76% * 76%
Construction	High Low	2820 0	99%
Service industries	High Low	0 407	36%

\* It has also been assumed that no women would have been in the 'high exposed' group in the mining and quarrying, electricity gas and steam and manufacturing industry sectors for arsenic, so these women (4,986 in number) have been allocated to the 'low exposed' group.

**(c) AF calculation**

For lung cancer associated with exposure to arsenic the estimated total (male and female) attributable fraction is 0.34% (95%CI=0.13%-0.73%), which equates to 113 deaths (95%CI=43-240) and 129 registrations (95%CI=49-274). The estimated AF for men is 0.48% (95%CI=0.23%-0.84%) resulting in 91 (95%CI=43-161) attributable deaths and 105 (95%CI=49-185), attributable registrations; and for women the AF is 0.16% (95%CI= 0.00%-0.58%) resulting in 22 (95%CI=0-79), attributable deaths and 24 (95%CI=0-89), attributable registrations (Table 22).

**Table 22** Summary results for occupational exposure to arsenic

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Lee-Feldstein (1986)	H	C-E	2.05	14074	1.4	0.09	68079	0.0035	0.0037	0.0016	0.0066	70	30	125	80	35	144
		H	F	2.05	2792	1	0.12	12673	0.0007	0.0007	0.0003	0.0012	13	6	23	15	6	27
		H	All		16866			80752	0.0042	0.0043	0.0019	0.0078	83	36	148	95	41	171
		L	C-E	1.74	2241	1.4	0.09	10841	0.0006	0.0004	0.0000	0.0015	8	0	29	9	0	33
		L	G-Q	1.74	147	0.9	0.11	551	0.0000	0.0000	0.0000	0.0001	0	0	1	0	0	2
		L	All		2388			11392	0.0006	0.0004	0.0000	0.0016	8	0	30	9	0	35
		All	All		19254			92144	0.0047	0.0048	0.0023	0.0084	91	43	161	105	49	185
Women	Lee-Feldstein (1986)	H	F	2.05	28	0.67	0.15	113	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H	All		28			113	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	C-E	1.74	5152	1.5	0.14	43345	0.0021	0.0015	0.0000	0.0056	21	0	77	24	0	86
		L	G-Q	1.74	260	0.8	0.15	1247	0.0001	0.0000	0.0000	0.0002	1	0	2	1	0	2
		L	All		5413			44592	0.0021	0.0016	0.0000	0.0058	22	0	79	24	0	89
		All	All		5441			44705	0.0021	0.0016	0.0000	0.0058	22	0	79	24	0	89

1. Specific scenario or main industry code – (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1



### 3.3 ASBESTOS

#### (a) Risk estimate

Goodman *et al.* (1999) reviewed 69 asbestos-exposed occupational cohorts, 42 in Europe, 22 in North America and the remainder elsewhere. The results of the study are therefore portable. The earliest study was published in 1967 and the most recent in 1997. The studies covered a variety of occupations, including: asbestos products manufacture (22%), cement workers (20%), shipyard workers (12%), asbestos miners and millers (10%) and textile workers (10%). The pooled analysis had 37 cohorts that provided results with latency and 55 without. Goodman suggests that the magnitude of the association between asbestos and lung cancer is frequently overestimated and that there are many different types and levels of exposure that resulted in a wide range of SMRs, the majority of occupational cohorts showing less than a two-fold increase in risk. Overall the meta-SMR for those studies without taking into account latency was 1.48 (95%CI=1.44-1.52), with a very high degree of heterogeneity ( $p < 0.0001$ ). This figure is used for the high group in CAREX.

Steenland *et al.* (1996) examined a subset of the papers in Goodman, plus some others, and derived a SMR of 2.0. However in view of Goodman's statement above his more conservative estimate is used. For low-level exposure we will use a SMR of 1.18 (95%CI=1.13-1.23) from Goodman, which was derived from the studies reporting the lowest percentages (0-0.6%) of mesothelioma deaths, i.e. an indication of low exposure to asbestos in the cohorts represented. Although not used to estimate overall AF (see below), these estimates of relative risk have been used to allocate estimated occupation attributable asbestos related lung cancers between industries.

An alternative method to that described in section 3.1 for calculating an attributable fraction has been used for lung cancer due to asbestos exposure. The number of excess deaths for lung cancer and for mesothelioma in job categories where there is known to have been exposure to asbestos, has been estimated based on the incidence of mesothelioma amongst workers in those job categories. The ratio of these excess lung cancers to mesotheliomas can then be taken as an indication of the numbers of lung cancers, which could be attributable to the exposure, and the AF is then derived from this. The method is applicable only to asbestos exposure, as mesothelioma is considered uniquely to be caused by exposure to asbestos. This method has the advantage that it takes account of the current impact that past levels of exposure to asbestos are known to be having on the incidence of cancer, by the direct link to mesothelioma deaths which are climbing rapidly, when lung cancer in general is declining due to the fall in the number of smokers. The link does, however, depend on the assumption that lung cancer has a similar pattern of latency to mesothelioma. Numbers of mesotheliomas for GB are obtained from the Mesothelioma Register. Although some mesotheliomas are considered to be due to low level para-occupational and environmental exposure, this is thought unlikely to be the case for lung cancer due to asbestos exposure so that all asbestos related lung cancers are assumed to be directly occupational in origin.

In populations with heavy asbestos exposures there have typically been at least as many, sometimes up to ten times as many, excess lung cancers as there have been mesotheliomas. The ratio depends on a range of factors - the most important of which are type of asbestos (the highest ratios have been linked to chrysotile exposure), level of exposure, age at exposure and smoking. Two lines of argument suggest that the ratio of asbestos related lung cancers to mesotheliomas in the British population as a whole is towards the lower end of the range of 1-10 estimated from the epidemiological studies. Firstly a study of lung cancer mortality in relation to indices of asbestos exposure and smoking habits in the west of Scotland suggested a ratio of around two asbestos lung cancers per mesothelioma for this region - which is known to be associated with fairly high asbestos exposures (Irvine *et al.*, 1993). Secondly, analyses of mesothelioma deaths in Great Britain by occupation and geographical area suggest that

substantial numbers of deaths may have arisen in workers other than those that were most heavily exposed (Rake *et al*, 2009)

More recent evidence suggests that the ratio may be at the bottom end of the range of 1-2 (Darnton *et al*, 2006). Asbestos is a more potent cause of mesothelioma than lung cancer and smoking is thought to interact with asbestos exposure in the causation of lung cancer. Thus in future the ratio of lung cancers to mesotheliomas is likely to fall, because the mesotheliomas will increasingly be generated by low exposure levels of asbestos that are less likely to cause lung cancer and because smoking levels have fallen since the 1960s (factors that, together, mean fewer lung cancers per mesothelioma). A recent analysis of lung cancer mortality for the whole of the Great Britain by occupational group in relation to indices of asbestos exposure and smoking habits suggested that the ratio of asbestos related lung cancer to mesothelioma deaths is between two-thirds and one (Darnton *et al*, 2006). The ratio of mesothelioma to lung cancer deaths in jobs exposed to asbestos used for the burden estimation is 1:1 (see Methodology Report Appendix 9), although this ratio, estimated for the period 1980-2000, may be decreasing as smoking and asbestos exposure levels both fall.

Using the alternative methodology that indicates a ratio of 1:1 for asbestos-related lung cancers and mesotheliomas, the attributable number of lung cancer deaths is therefore taken as equal to the number of mesotheliomas attributable to occupational plus para-occupational and environmental exposure (Table 24) (see the Mesothelioma Technical Report). For mesothelioma, deaths and registrations were assumed to be equal in number. For lung cancer, asbestos-attributable total registrations have been updated in proportion to the ratio of total (2004) lung cancer deaths to total (2005) registrations.

**(b) Numbers exposed**

Table 23 gives the number of workers exposed to asbestos by industry for the years 1990-1993 according to CAREX. For asbestos it has been assumed that only men have been exposed in the high exposure level categories. The low exposed numbers in the service industries have however been split between men and women, in the proportions of numbers employed at the 1991 Census in associate professional, technical, personal and customer service occupations<sup>9</sup>. However, the numbers (and proportions) exposed multiplied by excess risks (RR-1) using RRs for the high and low exposed groups (1.48 and 1.18 respectively) from the study by Goodman *et al* (1999) were used to weight the allocation of total attributable numbers between industries.

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<sup>9</sup> Standard Occupational Classification Major Groups 3, 6 and 7.

**Table 23** Numbers of workers exposed to asbestos according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Other mining	14,075	28,150	L
Manufacture of paper and paper products	577	119,050	H
Manufacture of industrial chemicals	1,006	130,000	H
Manufacture of other chemical products	1,077	175,175	H
Petroleum refineries	588	18,075	H
Manufacture of transport equipment	1,792	456,900	H
Electricity, gas and steam	304	140,975	H
Construction	46,096	1,753,450	H
Wholesale and retail trade and restaurants and hotels	4,046	4,459,525	L
Land transport	2,660	671,050	H
Sanitary and similar services	824	274,225	L
Personal and household services	22,066	686,750	L
<b>Total</b>	<b>95,111</b>	<b>8,913,325</b>	
<b>Main Industry Sector</b>		<b>% Male</b>	
Agriculture, hunting and forestry; fishing	High Low	0 0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High Low	5,344 14,075	100%
Construction	High Low	46,096 0	100%
Service industries	High Low	2,660 26,936	100% 38%

**(c) AF calculation**

For lung cancer and exposure to asbestos the estimated total (male and female) attributable fraction is 5.91% (95%CI=5.40%-6.40%), which equates to 1,937 (95%CI=1,770-2,100) deaths and 2,223 (95%CI=2,032-2,409) registrations. The estimated AF for men is 8.92% (95%CI=8.35%-9.50%) resulting in 1699 (95%CI=1,590-1,810) attributable deaths and 1956 (95%CI=1,830-2,083) attributable registrations; and for women the AF is 1.73% (95%CI=1.31%-2.11%) resulting in 238 (95%CI= 180-290) attributable deaths and 267 (95%CI= 202-326) attributable registrations (Table 24).

**Table 24** Summary results for occupational exposure to asbestos

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	N/A	All	All	N/A	78129	N/A	N/A	350302	0.0181	0.0892	0.0835	0.0950	1699	1590	1810	1956	1830	2083
Women	N/A	All	All	N/A	16982	N/A	N/A	82336	0.0039	0.0173	0.0131	0.0211	238	180	290	267	202	326

1. Specific scenario or main industry code -- (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.4 BERYLLIUM

#### (a) Risk estimate

Ward *et al.* (1992) reported results of a cohort mortality study of male workers from seven beryllium plants in the US. The SMR for lung cancer was 1.26 (95%CI=1.12-1.42; 280 observed, 221.5 expected) although significant excesses were only seen at two of the seven plants (in the towns of Lorain and Reading). The smoking-adjusted SMR for the entire cohort was 1.12 (95%CI=0.99-1.26; 280 observed, 250.8 expected) and this is used for the high exposure group. Due to the absence of sufficient dose-response data the risk estimate for low exposure was based on a harmonic mean of the high/low ratios across all other cancer-exposure pairs in the overall project where data were available. As this was less than 1 the RR for low exposure has been set to 1.

#### (b) Numbers exposed

Table 25 gives the numbers of workers exposed to beryllium by industry according to CAREX for 1990-1993. CAREX estimates about 11,000 workers are exposed to beryllium mostly in the manufacture of machinery except electrical (74.2%). The numbers have been allocated between men and women assuming that all are “blue collar” workers (in SOC major groups 3, 5 and 6).

**Table 25** Numbers of workers exposed to beryllium according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Crude petroleum and natural gas production	170	53,300	L
Manufacture of textiles	18	182,000	L
Manufacture of industrial chemicals	30	130,000	L
Manufacture of rubber products	4	53,025	L
Manufacture of glass and glass products	293	43,275	H
Manufacture of fabricated metal products, except machinery and equipment	586	292,200	H
Manufacture of machinery except electrical	8,163	692,275	H
Manufacture of electrical machinery, apparatus, appliances and supplies	695	473,750	H
Manufacture of transport equipment	466	456,900	H
Manufacture of instruments, photographic and optical goods	236	86,225	H
Electricity, gas and steam	122	140,975	H
Air transport	221	95,700	L
<b>Total</b>	<b>11,004</b>	<b>2,699,625</b>	
<b>Main Industry Sector</b>		<b>Male %</b>	
Agriculture, hunting and forestry; fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	10,561	76%
	Low	222	76%
Construction	High	0	
	Low	0	
Service industries	High	0	
	Low	221	65%

#### (c) AF calculation

For lung cancer related to exposure to beryllium the estimated total (male and female) attributable fraction is 0.02% (95%CI=0.00%-0.04%), which equates to 6 deaths (95%CI=0-14), and 7 (95%CI=0-16) registrations. The estimated AF for men is 0.02% (95%CI=0.00%-0.05%) resulting in 5 (95%CI=0-0) attributable deaths and 5 (95%CI=0-12) attributable registrations; and for women the AF is 0.01% (95%CI=0.00%-0.03%) resulting in 2 (95%CI=0-4), attributable deaths and 2 (95%CI=0-4) attributable registrations (Table 26).

**Table 26** Summary results for occupational exposure to beryllium

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Ward <i>et al.</i> (1992)	H	C-E	1.12	8026	1.4	0.09	38824	0.0020	0.0002	0.0000	0.0005	5	0	10	5	0	12
		H	All		8026			38824	0.0020	0.0002	0.0000	0.0005	5	0	10	5	0	12
		L	C-E	1	169	1.4	0.09	816	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	144	0.9	0.11	540	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		312			1356	0.0001	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		8339			40180	0.0021	0.0002	0.0000	0.0005	5	0	10	5	0	12
Women	Ward <i>et al.</i> (1992)	H	C-E	1.12	2535	1.5	0.14	21323	0.0010	0.0001	0.0000	0.0003	2	0	4	2	0	4
		H	All		2535			21323	0.0010	0.0001	0.0000	0.0003	2	0	4	2	0	4
		L	C-E	1	53	1.5	0.14	448	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	77	0.8	0.15	370	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		131			819	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		2665			22142	0.0011	0.0001	0.0000	0.0003	2	0	4	2	0	4

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.5 CADMIUM

#### (a) Risk estimate

Verougstraete *et al.* (2003) reviewed seven independent occupational cohorts (three UK, two Swedish, one US, one Chinese) totalling more than 12,000 workers. These studies were used by IARC to assess the carcinogenicity of Cadmium in 1993 (IARC, 1993b), and have since been updated. The studies are summarised below in Table 27.

**Table 27** Summary of results from occupational cadmium cohorts.

Study	Latest update	SMR (95%CI)	Obs/Exp
Ni-Cd Batteries, UK	Sorahan (1987)	1.30 (1.07-1.57)	110/84
Ni-Cd Batteries, SW	Jarup <i>et al.</i> (1998)	1.76 (1.01-2.87)	16/9.1
Cu-Cd Alloys	Sorahan <i>et al.</i> (Sorahan <i>et al.</i> , 1995)	1.01 (0.60-1.59)	18/17.8
Cd Recovery (Globe cohort)	Stayner <i>et al.</i> (1992a)	1.49 (0.95-2.22)	24/16.07
Cd processing	Kazantis & Blanks (1992); Kazantis <i>et al.</i> (1992)	1.12 (1.00-1.24)	339/304.1
	Inverse variance weighted average	1.19 (1.09-1.29)	

From the SMRs the inverse variance weighted average SMR was 1.19, which is used in the present study as the estimate of the AF for the high exposed workers.

Verougstraete *et al.* (2003) also summarised the exposure-response results for the five cohorts. From the studies the RR appears to be 1.0 or <1.0 for low-exposed groups, i.e. individuals who are exposed to between 250 and 500 $\mu\text{g}/\text{m}^3\cdot\text{y}$  of cadmium. An RR of 1 is therefore assumed for the low (background) exposure group.

#### (b) Numbers exposed

Table 28 gives the numbers of workers exposed to cadmium by industry according to CAREX for 1990-1993. CAREX estimates about 31,000 workers are exposed to cadmium, most of these working in construction (17.0%), non-ferrous metal basic industries (16.6%), personal and household services (9.2%) and manufacture of plastic products not elsewhere specified (8.6%). The UK Ni-Cd Batteries cohort reported on by Sorahan (1987) included 466 women in 3025 total workers, so it cannot be assumed all exposed workers in GB are men. The CAREX numbers are therefore split between men and women on the basis of the proportions in “blue collar” occupations at the 1991 Census.

**Table 28** Numbers of workers exposed to cadmium according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Manufacture of textiles	558	182000	L
Manufacture of wearing apparel, except footwear	7	189500	L
Manufacture of footwear	22	38500	L
Manufacture of wood, wood and cork products	28	132975	L
Printing, publishing and allied industries	1529	354750	L
Manufacture of industrial chemicals	1123	130000	H
Manufacture of other chemical products	14	175175	L
Petroleum refineries	184	18075	L
Manufacture of rubber products	499	53025	L
Manufacture of plastic products, nec	3113	136900	L
Manufacture of pottery, china and earthenware	474	54450	L
Manufacture of glass and glass products	452	43275	L
Manufacture of other non-metallic mineral products	1048	70875	L
Iron and steel basic industries			
Non-ferrous metal basic industries	5974	79325	H
Manufacture of fabricated metal products	2400	292200	L
Manufacture of machinery, except electrical	2327	692275	L
Manufacture of electrical machinery, apparatus, appliances	1224	473750	H
Manufacture of transport equipment	726	456900	L
Manufacture of instruments, photographic and optical	1246	86225	L
Other manufacturing industries	1180	59375	L
Electricity, gas and steam	622	140975	L
Construction	6103	1753450	L
Wholesale, retail trade and restaurants and hotels		4459525	
Air transport	792	95700	L
Services allied to transport	302	180725	L
Sanitary and similar services	741	274225	L
Personal and household services	3310	686750	L
<b>Total</b>	<b>35998</b>	<b>11,310,900</b>	
<b>Main Industry Sector</b>		<b>% Male</b>	
Agriculture, hunting and forestry; fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam	High	8321	76%
manufacturing industry	Medium	11343	76%
	Low	5086	
Construction	High	0	
	Low	6103	99%
Service industries	High	0	
	Low	5145	65%

**(c) AF calculation**

For lung cancer related to exposure to cadmium the estimated total (male and female) attributable fraction is 0.02% (95%CI=0.01%-0.04%), which equates to 8 (95%CI=4-12) deaths and 9 (95%CI=4-14) registrations. The estimated AF for men is 0.03% (95%CI=0.01%-0.05%) resulting in 6 (95%CI=3-9), attributable deaths and 7 (95%CI=3-10) attributable registrations; and for women the AF is 0.02% (95%CI=0.01%-0.02%) resulting in 2 (95%CI=1-3) attributable deaths and 2 (95%CI=1-4), attributable registrations (Table 29).



**Table 29** Summary results for occupational exposure to cadmium

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Verougstraete <i>et al.</i> (2003)	H	C-E	1.19	6324	1.4	0.09	30589	0.0016	0.0003	0.0001	0.0005	6	3	9	7	3	10
		H	All		6324			30589	0.0016	0.0003	0.0001	0.0005	6	3	9	7	3	10
		L	C-E	1	12486	1.4	0.09	60396	0.0031	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	F	1	6042	1	0.12	27426	0.0014	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	3344	0.9	0.11	12575	0.0006	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		21872			100397	0.0052	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		28196			130986	0.0068	0.0003	0.0001	0.0005	6	3	9	7	3	10
Women	Verougstraete <i>et al.</i> (2003)	H	C-E	1.19	1997	1.5	0.14	16800	0.0008	0.0002	0.0001	0.0002	2	1	3	2	1	4
		H	All		1997			16800	0.0008	0.0002	0.0001	0.0002	2	1	3	2	1	4
		L	C-E	1	3943	1.5	0.14	33171	0.0016	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	F	1	61	0.67	0.15	245	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	1801	0.8	0.15	8623	0.0004	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		5805			42038	0.0020	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		7802			58839	0.0028	0.0002	0.0001	0.0002	2	1	3	2	1	4

1. Specific scenario or main industry code -- (Table A1)

2. Relative risks selected from the best study

3. Numbers exposed, allocated to men/women

4. CAREX adjustment factor to mid-REP (Table A1)

5. Staff turnover (TO, Table A1)

6. Number ever exposed during the REP (Statistical Appendix equation 3)

7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)

8. Statistical Appendix equation 1

### 3.6 CHLOROMETHYL METHYL ETHER AND BIS(CHLOROMETHYL)ETHE

#### (a) Risk estimate

Since the 1970s the use of bis(chloromethyl) ether (BCME) and chloromethyl methyl ether (CMME) in the production of ion exchange resins has been restricted and safer handling procedures developed (IARC, 1974). A UK study published in 1983 found an SMR of 2.00 (95%CI=1.06-3.79) (McCallum *et al*, 1983).

#### (b) Numbers exposed

Only a few people in Britain have worked in the production of ion-exchange resins, and consequently been exposed to BCME and CMME. On the basis of industrial injury awards it appears that the annual number of attributable cases is two or less (HSC, 2001).

#### (c) AF calculation

The numbers of people exposed in GB are very small; therefore an AF calculation will not be done.

### 3.7 CHLORINATED TOLUENES AND BENZOYL CHLORIDE (COMBINED EXPOSURE)

#### (a) Risk estimate

As stated in section 2, small cohort studies of occupational combined exposure to  $\alpha$ CTs and BC in the US and England each noted an approximately three-fold excess of lung cancer (Sorahan *et al*, 1983, Sorahan and Cathcart, 1989, Wong, 1988).

#### (b) Numbers exposed

The number of workers exposed to these chemicals together is hard to determine, but considering the cohorts are very small then it can be assumed there are very few.

#### (c) AF calculation

The AF calculation will not be undertaken because of the small numbers involved.

### 3.8 CHROMIUM

#### (a) Risk estimate

Cole and Rodu (2005) reviewed 84 papers of 49 epidemiologic studies published since 1950, and undertook a range of meta-analyses relating chromium VI (CrVI) exposure to mortality. The conclusion was that CrVI was a weak lung carcinogen, when examining the studies that controlled for smoking. It has been postulated that the relationship is weak because of the lung's capacity to reduce CrVI to the non-carcinogenic CrIII (de Flora, 2000). The meta-analysis of 26 studies that controlled for smoking gave a meta-SMR of 1.18 (95%CI=1.12-1.25). This will be used for the estimate for the high group in the present study. Crump *et al*. (2003) also concluded that CrVI is a weak carcinogen, estimating that the lifetime additional risk of lung cancer mortality associated with 45 years of occupational exposure to  $1\mu\text{g}/\text{m}^3$  CrVI was 0.002. This is only about 5% of the minimum exposure ( $1.0\mu\text{g}/\text{m}^3\cdot\text{y}$ ) that consistently was associated with an increased lung cancer risk. This corresponds to a RR of about 1.0, which is used for the low (background) risk group.

#### (b) Numbers exposed

Table 30 gives the numbers of workers exposed to chromium by industry according to CAREX for 1990-1993. CAREX estimates about 130,000 workers were exposed to the metal in 1990-93, most of these occurring in the manufacture of fabricated metal products (16.2%), of machinery except electrical (17.5%) and transport equipment (11.1%). Assuming that all are employed in "blue collar" occupations, the numbers have been split between men and

women according to the proportions in these occupations in the relevant grouped industrial sectors from 1991 Census data. Numbers employed in 'Iron and steel basic industries' have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers.

**Table 30** Numbers of workers exposed to chromium according to CAREX in 1990-1993.

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Crude petroleum and natural gas production	1198	53300	L
Food manufacturing	2049	414150	L
Beverage industries	264	88100	L
Manufacture of textiles	3286	182000	H
Manufacture of wearing apparel, except footwear	1012	189500	H
Manufacture of leather and products of leather	554	16825	H
Manufacture of footwear	108	38500	H
Manufacture of wood, wood and cork products	3020	132975	H
Manufacture of furniture and fixtures	138	144325	H
Manufacture of paper and paper products	1802	119050	L
Printing, publishing and allied industries	3634	354750	L
Manufacture of industrial chemicals	3020	130000	H
Manufacture of other chemical products	1626	175175	H
Petroleum refineries	874	18075	L
Manufacture of rubber products	928	53025	H
Manufacture of plastic products, nec	3408	136900	H
Manufacture of pottery, china and earthenware	250	54450	H
Manufacture of glass and glass products	609	43275	H
Manufacture of other non-metallic mineral products	169	70875	H
Iron and steel basic industries	680	48425	H
Non-ferrous metal basic industries	2368	79325	H
Manufacture of fabricated metal products	21038	292200	H
Manufacture of machinery, except electrical	22792	692275	H
Manufacture of electrical machinery, apparatus, appliances	5443	473750	L
Manufacture of transport equipment	14482	456900	H
Manufacture of instruments, photographic and optical	1651	86225	L
Other manufacturing industries	620	59375	H
Electricity, gas and steam	660	140975	H
Construction	4264	1753450	H
Land transport	1528	671050	L
Water transport	1026	68175	L
Air transport	4328	95700	L
Services allied to transport	74	180725	L
Sanitary and similar services	448	274225	L
Personal and household services	20687	686750	L
<b>Total</b>	<b>130038*</b>	<b>16,299,700</b>	
<b>Main Industry Sector</b>		<b>% Male</b>	
Agriculture, hunting and forestry; fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	65946	76%
	Medium	13482	76%
	Low	17575	76%
Construction	High	0	
	Medium	4264	99%
	Low		
Service industries	High	0	
	Low	28091	65%

\* includes workers in iron and steel basic industries (excluded from the analysis)

**(c) AF calculation**

For lung cancer related to exposure to chromium the estimated total (male and female) attributable fraction is 0.18% (95%CI=0.12%-0.25%), which equates to 58 (95%CI=38-81) deaths and 67 (95%CI=44-92) registrations. The estimated AF for men is 0.22% (95%CI=0.15%-0.31%) resulting in 43 (95%CI=28-59) attributable deaths and 49 (95%CI=32-68) attributable registrations; and for women the AF is 0.11% (95%CI=0.07%-0.16%) resulting in 16 (95%CI=10-22) attributable deaths and 18 (95%CI=12-24) attributable registrations (Table 31).

**Table 31** Summary results for occupational exposure to chromium

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
<b>Men</b>	Cole and Rodu (2005)	H	C-E	1.18	50119	1.4	0.09	242428	0.0125	0.0022	0.0015	0.0031	43	28	59	49	32	68
		H	All		50636			244928	0.0126	0.0022	0.0015	0.0031	43	28	59	49	32	68
	Crump <i>et al.</i> (2003)	L	C-E	1	23603	1.4	0.09	114171	0.0059	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	F	1	4221	1	0.12	19162	0.0010	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	18259	0.9	0.11	68656	0.0035	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		46084			201989	0.0104	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		96203			444417	0.0229	0.0022	0.0015	0.0031	43	28	59	49	32	68
<b>Women</b>	Cole and Rodu (2005)	H	C-E	1.18	15827	1.5	0.14	133147	0.0063	0.0011	0.0007	0.0016	16	10	22	18	12	24
		H	All		15990			134520	0.0064	0.0011	0.0007	0.0016	16	10	22	18	12	24
	Crump <i>et al.</i> (2003)	L	C-E	1	7454	1.5	0.14	62705	0.0030	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	F	1	43	0.67	0.15	171	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	9832	0.8	0.15	47079	0.0022	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		17328			109955	0.0052	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		33155			243102	0.0116	0.0011	0.0007	0.0016	16	10	22	18	12	24

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.9 COBALT

#### (a) Risk estimate

A nested case-control study in a French hard-metal industry cohort covering 10 facilities found a significantly raised risk of lung cancer associated with simultaneous exposure to cobalt and tungsten carbide (OR=1.93, 95%CI=1.03–3.62). The odds ratio increased with cumulative exposure (first quartile OR=1.00, second quartile OR=2.64, third quartile OR=2.59, fourth quartile OR=4.13) and with duration of exposure. Adjustment for smoking did not alter the OR estimates (Moulin *et al*, 1998). A job-exposure matrix was used to assess occupational exposures. The two-fold raised risk found was confirmed in a further study of the largest production site of the ten for which individual job histories were available, with an SMR=2.02 (95%CI=1.32-2.96) for exposure to hard metal dust was used to estimate the OR above (i.e at an exposure score >1, on a scale of 1 to 9) (Wild et al, 2000). For the present study the industry-wide OR of 1.93 (95%CI=1.03-3.62) for those with these exposure scores was used for the estimate of AF for the higher exposure group. For the lower exposure group, the overall SMR for lung cancer (i.e. including those exposed at a score of 0 or 1) of 1.30 (95%CI=1.00-1.66) was used.

#### (b) Numbers exposed

The number of workers exposed to cobalt from CAREX, are given in Table 32. Those judged to be potentially exposed to high levels of cobalt or cobalt compounds (NTP ROC Substance Profile, cobalt sulphate) are workers in hard-metal, coal and metal mining, smelting and refining, cobalt dye painting and cobalt chemical production industries, plus limited exposure from cobalt containing paint driers. It has been assumed that other workers exposed to cobalt in the CAREX numbers were split between men and women on the basis of employment in “blue collar” jobs from the 1991 Census. Numbers employed in ‘Iron and steel basic industries’ have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers (see Section 3.25).

**Table 32** Numbers of workers exposed to cobalt and its compounds in British industries according to CAREX 1990-1993

Industry	CAREX Data 1990-1993		
	Number Exposed	Number in Industry	Exposure Level
Agriculture and hunting			
Crude petroleum and natural gas production	47	53300	L
Food manufacturing	2224	414150	L
Beverage industries	32	88100	L
Manufacture of textiles	146	182000	L
Manufacture of wearing apparel, except footwear	584	189500	L
Manufacture of leather and products of leather or of its	8	16825	L
Manufacture of wood and wood and cork products, except	1338	132975	L
Manufacture of furniture and fixtures, except primary of	4417	144325	L
Manufacture of paper and paper products	371	119050	L
Printing, publishing and allied industries	2512	354750	L
Manufacture of industrial chemicals	1154	130000	H
Manufacture of other chemical products	1870	175175	H
Petroleum refineries	13	18075	L
Manufacture of rubber products	26	1125	L
Manufacture of plastic products not elsewhere classified	414	136900	L
Manufacture of pottery, china and earthenware	474	54450	L
Manufacture of glass and glass products	510	43275	L
Manufacture of other non-metallic mineral products	27	70875	L
Iron and steel basic industries	693	48425	L
Non-ferrous metal basic industries	1097	79325	H
Manufacture of fabricated metal products, except	6318	292200	L
Manufacture of machinery except electrical	3108	692275	L
Manufacture of electrical machinery, apparatus, appliances	368	473750	L
Manufacture of transport equipment	2326	456900	L
Manufacture of instruments, photographic and optical	1022	86225	L
Other manufacturing industries	234	59375	L
Electricity, gas and steam	146	140975	L
Construction	2699	1,753,450	L
Air transport	1264	95700	L
Services allied to transport	230	180725	L
Sanitary and similar services	47	274225	L
<b>TOTAL</b>	<b>35,719*</b>	<b>7,204,950</b>	
Main Industry Sector		% Male	
Agriculture, hunting & forestry, fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	4,121	76%
	Low	27,212	76%
Construction	High	0	
	Low	2,699	99%
Service industries	High	0	
	Low	1541	65%

\* includes workers in iron and steel basic industries (excluded from the analysis)

**(c) AF calculation**

For lung cancer related to exposure to cobalt the estimated total (male and female) attributable fraction is 0.19% (95%CI=0.05%-0.39%), which equates to 63 deaths

(95%CI=16-128) and 73 (95%CI=18-147) registrations. The estimated AF for men is 0.25% (95%CI= 0.06%-0.50%) resulting in 47 (95%CI=12-95) attributable deaths and 54 (95%CI=14-110) attributable registrations; and for women the AF is 0.12% (95%CI=0.03%-0.24%) resulting in 16 (95%CI=4-33) attributable deaths and 18 (95%CI=5-37) attributable registrations (Table 33).



**Table 33** Summary results for occupational exposure to cobalt

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Moulin <i>et al.</i> (1998)	H	C-E	1.93	3132	1.4	0.09	15149	0.0008	0.0007	0.0000	0.0020	14	0	39	16	1	44
		H	All		3132			15149	0.0008	0.0007	0.0000	0.0020	14	0	39	16	1	44
		L	C-E	1.3	20265	1.4	0.09	98025	0.0051	0.0015	0.0000	0.0034	29	1	65	33	1	75
		L	F	1.3	2672	1	0.12	12129	0.0006	0.0002	0.0000	0.0004	4	0	8	4	0	9
		L	G-Q	1.3	1002	0.9	0.11	3766	0.0002	0.0001	0.0000	0.0001	1	0	2	1	0	3
		L	All		23939			113920	0.0059	0.0018	0.0000	0.0039	33	1	75	39	1	87
		All	All		27071			129070	0.0067	0.0025	0.0006	0.0050	47	12	95	54	14	110
Women	Moulin <i>et al.</i> (1998)	H	C-E	1.93	989	1.5	0.14	8320	0.0004	0.0004	0.0000	0.0010	5	0	14	6	0	16
		H	All		989			8320	0.0004	0.0004	0.0000	0.0010	5	0	14	6	0	16
		L	C-E	1.3	6400	1.5	0.14	53838	0.0026	0.0008	0.0000	0.0017	11	0	24	12	0	27
		L	F	1.3	27	0.67	0.15	108	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1.3	539	0.8	0.15	2583	0.0001	0.0000	0.0000	0.0001	1	0	1	1	0	1
		L	All		6966			56528	0.0027	0.0008	0.0000	0.0018	11	0	25	12	0	28
		All	All		7955			64849	0.0031	0.0012	0.0003	0.0024	16	4	33	18	5	37

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.10 CRYSTALLINE SILICA

#### (a) Risk estimate

A review of occupational carcinogens by Steenland *et al.* (1996) included 13 cohort and case-control studies of silica-exposed workers and obtained a combined RR of 1.33 (95%CI=1.21-1.45). Steenland *et al.* (2001) also conducted a pooled exposure-response analysis of 10 silica-exposed cohorts to investigate lung cancer. They estimated an average SMR of 1.2 (95%CI=1.1-1.3). Categorical analysis of cumulative exposure resulted in a monotonic trend with ORs. The OR for the second quintile of cumulative exposure (between 0.4 and 2.0 mg/m<sup>3</sup>.years) was 1.0 (95%CI=0.85-1.30). They estimated that the excess lifetime risk (through age 75) of lung cancer for a worker exposed from age 20 to 65 at 0.1 mg/m<sup>3</sup>.respirable crystalline silica was 1.1-1.7%, above background risks of 3-6%.

Kurihara and Wada (2004) undertook a meta-analysis of 17 cohorts and 13 case-control studies published between 1966 and 2001 that examined the relationship between silica, silicosis and lung cancer. The analysis included more studies than Steenland's review and pooled analysis, and also took into account the presence/absence of silicosis:

Overall:	RR=1.32 (95%CI=1.24-1.41)
Lung cancer in the presence of silicosis:	RR=2.37 (95%CI=1.98-2.84) based on silicotics in 11 cohort and 5 case-control studies
Lung cancer in the absence of silicosis:	RR=0.96 (95%CI=0.81-1.15) based on non-silicotic subjects from 6 cohort and 2 case-control studies

Pelucchi *et al.* (2006) undertook a systematic review of studies published since the 1997 IARC monograph (IARC, 1997a), which included 28 cohort, 15 case-control and two PMR studies. Their pooled RR, calculated using random effects models from all the cohort studies was 1.34 (95%CI=1.25-1.45). From case-control studies the pooled RR was 1.41 (95%CI=1.18-1.67) and for PMR studies was 1.24 (95%CI=1.05-1.47). Results for studies where silicosis status was known and unknown were similar to those found by Kurihara and Wada. For the present study Kurihara and Wada's overall estimate (which was for men) is therefore used for the high exposed group (RR=1.32, 95%CI=1.24-1.41); the low exposed group are assumed to have a RR of 1.0 from the study of Steenland *et al.* (2001).

#### (b) Numbers exposed

Table 34 gives the numbers of workers exposed to crystalline silica by industry according to CAREX for 1990-1993. All of the exposed workers were assumed to be in 'blue collar' occupations for the male/female split; workers employed in 'Iron and steel basic industries' have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers.

**Table 34** Numbers of workers exposed to crystalline silica according to CAREX 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Crude petroleum and natural gas production	1670	53300	L
Metal ore mining	1161	1225	H
Other mining	16240	28150	H
Food manufacturing	360	414150	L
Beverage industries	24	88100	L
Tobacco manufacture	1	9950	L
Manufacture of textiles	338	182000	L
Manufacture of wearing apparel, except footwear	494	189500	L
Manufacture of leather and products of leather or of its substitutes	158	16825	L
Manufacture of footwear	100	38500	L
Manufacture of furniture and fixture, except primary of metal	398	144325	L
Printing, publishing and allied industries	756	354750	L
Manufacture of industrial chemicals	618	130000	H
Manufacture of other chemical products	5662	175175	H
Petroleum refineries	114	18075	L
Manufacture of miscellaneous products of petroleum and coal	290	1125	H
Manufacture of rubber products	703	53025	L
Manufacture of plastic products nec	1750	136900	L
Manufacture of pottery, china and earthenware	21769	54450	H
Manufacture of glass and glass products	6932	43275	H
Manufacture of other non-metallic mineral products	24406	70875	H
Iron and steel basic industries	3853	48425	H
Non-ferrous metal basic industries	2406	79325	H
Manufacture of fabricated metal products, except machinery and equipment	8002	292200	H
Manufacture of machinery except electrical	16253	692275	H
Manufacture of transport equipment	6420	456900	H
Manufacture of instruments, photographic and optical goods	1567	86225	L
Other manufacturing industries	1316	59375	H
Electricity, gas and steam	3382	140975	H
Construction	449930	1753450	H
Land transport	5123	671050	L
Water transport	1193	68175	L
Air transport	702	95700	L
Services allied to transport	588	180725	L
Sanitary and similar services	3760	274225	L
Education services	610	1455875	L
Research and scientific institutes	880	91100	L
<b>Total</b>	<b>589929*</b>	<b>8,649,675</b>	
<b>Main Industry Sector</b>		Male %	
Agriculture, hunting and forestry; fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	114857	76%
	Low	8433	
Construction	High	449930	99%
	Low	0	
Service industries	High	0	
	Low	12856	65%

\* includes workers in iron and steel basic industries (excluded from the analysis)

**(c) AF calculation**

For lung cancer related to exposure to crystalline silica the estimated total (male and female) attributable fraction is 2.41% (95%CI=1.80%-3.04%), which equates to 789 (95%CI= 592-998) deaths and 907 (95%CI=680-1,147) registrations. The estimated AF for men is 3.90% (95%CI=2.93%-4.93%) resulting in 743 (95%CI=559-939) attributable deaths and 856 (95%CI=643-1,081) attributable registrations; and for women the AF is 0.33% (95%CI=0.24%-0.43%) resulting in 45 (95%CI=33-59) attributable deaths and 51 (95%CI=37-67) attributable registrations (Table 35).

**Table 35** Summary results for occupational exposure to crystalline silica

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Kurihara and Wada (2004)	H	C-E	1.32	91120	1.4	0.09	440750	0.0227	0.0070	0.0052	0.0088	133	100	168	153	115	193
		H	F	1.32	445431	1	0.12	2021946	0.1042	0.0320	0.0241	0.0404	610	459	770	703	528	886
		H	All		536550			2462696	0.1269	0.0390	0.0293	0.0492	743	558	938	856	643	1079
	Steenland <i>et al.</i> (2001)	L	C-E	1	6409	1.4	0.09	31001	0.0016	0.0000	0.0000	0.0004	0	0	7	0	0	8
		L	G-Q	1	8356	0.9	0.11	31421	0.0016	0.0000	0.0000	0.0004	0	0	7	0	0	8
		L	All		14765			62422	0.0032	0.0000	0.0000	0.0007	0	0	14	0	0	16
		All	All		551316			2525118	0.1302	0.0390	0.0293	0.0493	743	559	939	856	643	1081
Women	Kurihara and Wada (2004)	H	C-E	1.32	23737	1.5	0.14	199695	0.0095	0.0030	0.0023	0.0039	42	31	53	47	35	60
		H	F	1.32	4499	0.67	0.15	18043	0.0009	0.0003	0.0002	0.0003	4	3	5	4	3	5
		H	All		28237			217738	0.0104	0.0033	0.0025	0.0042	45	34	58	51	38	65
	Steenland <i>et al.</i> (2001)	L	C-E	1	2024	1.5	0.14	17027	0.0008	0.0000	0.0000	0.0002	0	0	3	0	0	3
		L	G-Q	1	4500	0.8	0.15	21546	0.0010	0.0000	0.0000	0.0002	0	0	3	0	0	4
		L	All		6524			38572	0.0018	0.0000	0.0000	0.0004	0	0	6	0	0	7
		All	All		34760			256311	0.0122	0.0033	0.0024	0.0043	45	33	59	51	37	67

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.11 DIESEL ENGINE EXHAUST

#### (a) Risk estimate

Lipsett and Campleman (1999) undertook a meta-analysis of 30 studies to investigate the relationship between occupational diesel exhaust exposure (DEE) and lung cancer. There was substantial heterogeneity in the pooled risk estimates for all studies combined and for most subsets. However, a meta-analysis of 12 studies (20 risk estimates) that had adjusted for smoking showed little evidence of heterogeneity. The authors also carried out sensitivity analyses by excluding studies in which exposures to exhaust from diesel versus conventional internal combustion exposures could not be easily distinguished. For the present study the pooled smoking-adjusted RR was 1.47 (95%CI=1.29-1.67), and has been chosen for the high exposure risk estimate. For the low estimate we have used that from Coggon *et al.* (1984) of 1.1 (95%CI=0.7-1.8), a large UK-based death-certificate study.

#### (b) Numbers exposed

Table 36 gives the numbers of workers exposed to diesel engine exhaust by industry according to CAREX for 1990-1993. Numbers are allocated between men and women in mining and manufacturing and in construction assuming that all the exposed were employed in “blue collar” occupations. However for the service sector, as the large numbers exposed at a high level are all in land transport and its allied services, the numbers have been allocated between men and women only on the basis of those employed as plant and machine operatives (SOC major group 8), which specifically covers those employed as road and other transport operatives. Numbers employed in ‘iron and steel basic industries have been excluded from the calculation to avoid double-counting their risk with ‘steel foundry workers’.

**Table 36** Numbers of workers exposed to diesel engine exhaust according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Crude petroleum and natural gas production	7530	53300	L
Metal ore mining	645	1225	H
Other mining	14075	28150	H
Food manufacturing	3860	414150	L
Beverage industries	4660	88100	L
Tobacco manufacture	12	9950	L
Manufacture of textiles	1009	182000	L
Manufacture of wearing apparel, except footwear	1120	189500	L
Manufacture of wood and wood and cork products, except furniture	4016	132975	L
Manufacture of furniture and fixture, except primary of metal	504	144325	L
Manufacture of paper and paper products	1144	119050	L
Printing, publishing and allied industries	595	354750	L
Manufacture of industrial chemicals	1587	130000	L
Manufacture of other chemical products	1387	175175	L
Petroleum refineries	826	18075	L
Manufacture of miscellaneous products of petroleum and coal	39	1125	L
Manufacture of plastic products nec	293	136900	L
Manufacture of glass and glass products	105	43275	L
Manufacture of other non-metallic mineral products	11613	70875	L
Iron and steel basic industries	957	48425	L
Non-ferrous metal basic industries	2653	79325	L
Manufacture of fabricated metal products, except machinery and equipment	3920	292200	L
Manufacture of machinery except electrical	3156	692275	L
Manufacture of electrical machinery, apparatus, appliances and supplies	1224	473750	L
Manufacture of transport equipment	2574	456900	L
Manufacture of instruments, photographic and optical goods	154	86225	L
Other manufacturing industries	326	59375	L
Electricity, gas and steam	3795	140975	L
Water works and supply	4095	45175	L
Construction	106658	1753450	H
Wholesale and retail trade and restaurants and hotels	13487	4459525	L
Land transport	158534	671050	H
Water transport	12993	68175	L
Air transport	6772	95700	L
Services allied to transport	14778	180725	H
Communication	6277	459425	L
Public administration and defence	2504	1557875	L
Sanitary and similar services	4229	274225	L
Personal and household services	68956	686750	L
<b>Total, excluding iron and steel basic industries</b>	<b>472105</b>	<b>12,647,250</b>	
<b>Main Industry Sector</b>		<b>% Male</b>	
Agriculture, hunting and forestry; fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	14,720	76%
	Low	62,197	76%
Construction	High	106,658	99%
	Low		
Service industries	High	173,312	88%
	Low	115,218	65%

**(c) AF calculation**

For lung cancer related to exposure to diesel engine exhaust the estimated total (male and female) attributable fraction is 1.84% (95%CI=0.00%-3.37%), which equates to 605 (95%CI=272-1,107) deaths and 695 (95%CI=313-1,269) registrations. The estimated AF for men is 2.90% (95%CI=1.43%-4.81%) resulting in 552 (95%CI=272- 917) attributable deaths and 635 (95%CI=313-1,055) attributable registrations; and for women the AF is 0.39% (95%CI=0.00%-1.38%) resulting in 53 (95%CI=0-190), attributable deaths and 60 (95%CI=0-214) attributable registrations (Table 37).



**Table 37** Summary results for occupational exposure to diesel engine exhaust

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Lipsett and Campleman (1999)	H	C-E	1.47	14426	1.4	0.09	69777	0.0036	0.0016	0.0010	0.0023	31	20	44	36	23	51
		H	F	1.47	105591	1	0.12	479312	0.0247	0.0113	0.0071	0.0160	215	135	304	247	155	350
		H	G-Q	1.47	152515	0.9	0.11	573469	0.0296	0.0135	0.0085	0.0191	257	161	363	296	185	418
		H	All		272532			1122558	0.0579	0.0264	0.0166	0.0374	503	315	711	579	363	819
	Coggon <i>et al.</i> (1984)	L	C-E	1.1	47270	1.4	0.09	228646	0.0118	0.0011	0.0000	0.0087	22	0	166	25	0	191
		L	G-Q	1.1	74892	0.9	0.11	281600	0.0145	0.0014	0.0000	0.0106	27	0	201	31	0	232
		L	All		122161			510246	0.0263	0.0026	0.0000	0.0193	49	0	367	56	0	422
		All	All		394693			1632804	0.0842	0.0290	0.0143	0.0481	552	272	917	635	313	1055
Women	Lipsett and Campleman (1999)	H	C-E	1.47	294	1.5	0.14	2477	0.0001	0.0001	0.0000	0.0001	1	0	1	1	1	1
		H	F	1.47	1067	0.67	0.15	4277	0.0002	0.0001	0.0001	0.0001	1	1	2	1	1	2
		H	G-Q	1.47	20797	0.8	0.15	99586	0.0047	0.0022	0.0014	0.0032	31	19	44	34	21	49
		H	All		22158			106340	0.0051	0.0024	0.0015	0.0034	33	20	47	37	23	52
	Coggon <i>et al.</i> (1984)	L	C-E	1.1	14927	1.5	0.14	125578	0.0060	0.0006	0.0000	0.0045	8	0	63	9	0	70
		L	G-Q	1.1	40326	0.8	0.15	193098	0.0092	0.0009	0.0000	0.0069	13	0	95	14	0	106
		L	All		55254			318676	0.0152	0.0015	0.0000	0.0114	21	0	157	23	0	177
		All	All		77412			425017	0.0202	0.0039	0.0000	0.0138	53	0	190	60	0	214

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.12 EPICHLOROHYDRIN

#### (a) Risk estimate

As stated in section 2 the evidence for the carcinogenicity of ECH is unconvincing. Therefore, ECH was not included in the AF calculation.

#### (b) Numbers exposed

There are no figures available that indicate the number of workers that may be exposed to ECH.

#### (c) AF calculation

This has not been carried out.

### 3.13 ENVIRONMENTAL TOBACCO SMOKE

#### (a) Risk estimate

Zhong *et al.* (2000) carried out a meta-analysis of 35 case-control and five cohort studies providing quantitative estimates of the association between lung cancer and exposure to ETS, published between 1981 and 1999. They used fixed- and random-effects models to calculate pooled estimates of relative risk for men and women, for non-smokers living with a smoker and non-smokers exposed to ETS at work. Below is a summary of the results (no heterogeneity found) of non-smokers exposed to ETS at work:

Women:	14 case-control studies	OR=1.15 (95%CI=1.04-1.28)
Men:	5 case-control studies	OR=1.29 (95%CI=0.93-1.78)
Total:		OR=1.16 (95%CI=1.05-1.28)

Brennan *et al.* (2004) carried out a pooled analysis of two large case-control studies of lung cancer, one from the US and the second from Europe (Germany, Italy, Sweden, Spain, France, Portugal, UK). Subjects included 1,263 never smoking lung cancer cases and 2,740 population and hospital controls. The OR for 'ever exposed' to ETS from the workplace, after adjustment, was 1.16 (95%CI=0.99-1.36). Boffetta (2002) also carried out a meta-analysis and obtained a meta-RR of 1.17 (95%CI=1.04-1.32). These two studies give results similar to the meta-analysis by Zhong. In the present study estimates from Zhong are thus used for men and women, for the high exposure groups. Due to the absence of sufficient dose-response data the risk estimate for low exposure was based on a harmonic mean of the high/low ratios across all other cancer-exposure pairs in the overall project where data were available. As this was less than 1 the RR for low exposure has been set to 1.

#### (b) Numbers exposed

Table 38 gives the numbers of workers exposed to environmental tobacco smoke by industry according to CAREX for 1990-1993. The exposed numbers have been divided between men and women on the assumption that those included in the CAREX data in agriculture, forestry and fishing were only those employed in "white collar" managerial, professional, administrative and secretarial (office-based) jobs<sup>10</sup>, but all occupations were assumed to be included for the other industry sectors.

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<sup>10</sup> "White collar" jobs are taken to include those in the Standard Occupational Classification Major Groups 1, 2 and 4.

**Table 38** Numbers of workers exposed to environmental tobacco smoke according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Agriculture & hunting	8396	419825	L
Forestry & logging	580	14500	L
Food manufacturing	8288	414150	L
Manufacture of textiles	5470	182000	L
Manufacture of wearing apparel, except footwear	11370	189500	L
Manufacture of wood & wood/cork products, except furniture	1330	132975	L
Manufacture of paper & paper products	3572	119050	L
Printing, publishing & allied industries	31922	354750	L
Manufacture of industrial chemicals	6497	130000	L
Manufacture of other chemical products	10520	175175	L
Petroleum refineries	2528	18075	L
Manufacture of plastic products nec	12326	136900	L
Manufacture of pottery, china & earthenware	3267	54450	L
Manufacture of glass & glass products	2596	43275	L
Manufacture of other non-metallic mineral products	4255	70875	L
Iron and steel basic industries	4601	48425	L
Manufacture of fabricated metal products, except machinery & equipment	17537	292200	L
Manufacture of machinery except electrical	62301	692275	L
Manufacture of electrical machinery, apparatus, appliances & supplies	23692	473750	L
Manufacture of transport equipment	56208	456900	L
Manufacture of instruments, photographic & optical goods	12926	86225	L
Other manufacturing industries	5344	59375	L
Electricity, gas & steam	12691	140975	L
Construction	102195	1753450	H
Wholesale & retail trade & restaurants and hotels	424031	4459525	H
Land transport	10775	671050	H
Water transport	13633	68175	H
Air transport	40196	95700	H
Services allied to transport	21690	180725	H
Communication	24542	459425	H
Financing, insurance, real estate & business services	119385	2830800	H
Public administration & defence	71699	1557875	H
Sanitary & similar services	10970	274225	H
Education services	14553	1455875	H
Research & scientific institutes	3644	91100	H
Medical, dental, other health & veterinary services	17728	1435675	L
Welfare institutions	18452	741375	H
Business, professional & other organisation	2776	133075	H
Recreational & cultural services	32079	534600	H
Personal & household services	78059	686750	H
<b>Total</b>	<b>1314624</b>	<b>22,135,025</b>	
<b>Main Industry Sector</b>		<b>% Male</b>	
			<b>Female</b>
Agriculture, hunting and forestry; fishing	High	0	
	Low	8976	836
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	0	
	Low	299241	42522
Construction	High	102195	4507
	Low	0	
Service industries	High	886484	234564

**Table 38** Numbers of workers exposed to environmental tobacco smoke according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Low	17728		4691

Only non-smokers are considered as being at risk from lung cancer due to occupational exposure to environmental tobacco smoke, and only these are used in the AF calculation. The numbers exposed have therefore been adjusted using estimates of those who have ‘never or only occasionally smoked cigarettes’, by sex for 1974 from the General Household Survey (GHS) (Goddard and Green, 2005). This is the earliest year for which data is available from the GHS, and the most representative of the proportion of non-smokers during the relevant exposure period. The estimates were 25% for men and 49% for women. These proportions have increased steadily since 1984.

**(c) AF calculation**

For lung cancer related to exposure to environmental tobacco smoke the estimated total (male and female) attributable fraction is 0.76% (95%CI=0.08%-1.755), which equates to 249 (95%CI=27-574) deaths and 284 (95%CI=30-655) registrations. The estimated AF for men is 0.73% (95%CI=0.00%-1.95%) resulting in 138 (95%CI=0-370) attributable deaths and 159 (95%CI=0-426) attributable registrations; and for women the AF is 0.81% (95%CI=0.20%-1.48%) resulting in 111 (95%CI=27-203) attributable deaths and 125 (95%CI=30-228) attributable registrations (Table 39).

**Table 39** Summary results for occupational exposure to environmental tobacco smoke

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
<b>Men</b>	Zhong <i>et al.</i> (2000)	H	F	1.29	23249	1	0.12	105536	0.0054	0.0016	0.0000	0.0042	30	0	80	34	0	92
		H	G-Q	1.29	101946	0.9	0.11	383325	0.0198	0.0057	0.0000	0.0153	108	0	290	125	0	334
		H	All		125195			488861	0.0252	0.0073	0.0000	0.0195	138	0	370	159	0	426
		L	A-B	1	1818	1	0.07	4966	0.0003	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	C-E	1	53115	1.4	0.09	256921	0.0132	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	2039	0.9	0.11	7666	0.0004	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		56972			269553	0.0139	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		182167			758415	0.0391	0.0073	0.0000	0.0195	138	0	370	159	0	426
<b>Women</b>	Zhong <i>et al.</i> (2000)	H	F	1.15	4507	0.67	0.15	18074	0.0009	0.0001	0.0000	0.0002	2	0	3	2	0	4
		H	G-Q	1.15	234564	0.8	0.15	1123184	0.0535	0.0080	0.0019	0.0145	109	26	200	123	30	225
		H	All		239070			1141257	0.0543	0.0081	0.0020	0.0148	111	27	203	125	30	228
		L	A-B	1	836	0.75	0.1	2570	0.0001	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	C-E	1	42522	1.5	0.14	357724	0.0170	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	4691	0.8	0.15	22462	0.0011	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		48049			382755	0.0182	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		287119			1524013	0.0726	0.0081	0.0020	0.0148	111	27	203	125	30	228

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.14 IONISING RADIATION

#### (a) Risk estimate

Airline cockpit crews are occupationally exposed to ionising radiation (IR) of cosmic origin. Radiation workers in the nuclear industry and medical and laboratory staff are the other principal group exposed. The relative risks for occupational exposure to ionising radiation were obtained from UNSCEAR, 2006 (UNSCEAR, 2008), using models of excess relative risk (ERR) per unit of radiation dose, estimated as  $RR=1+ERR$ . Details of the model used are as follows:

From UNSCEAR 2006, Table 51, generalized ERR incidence model, linear dose response:

$$ERR(a) = \alpha \cdot D \cdot \exp(\kappa_1 \cdot I_{s=\text{female}}),$$

where  $\alpha = 3.182\ 24 \times 10^{-1} \text{ Sv}^{-1}$

$$\kappa_1 = 1.480\ 8$$

From Table D9 in the UNSCEAR report: Model Deviance = 6,181.503, df = 42,695

ERR is obtained as average ERR(a), averaged over a = 25-100 (long latency REP 1956-1995).

Dose was assumed to be an individual's cumulative dose received over the risk exposure period (REP) for each cancer (1956-1995 for the solid tumours). For workers exposed to ionising radiation, doses were estimated using data from the Central Index of Dose Information (CIDI, see below). To estimate lifetime dose from the CIDI data, the following procedure was used. Data on collective doses for the years 1990 to 2004 were used to estimate total collective dose for the REP, by assuming a constant 1990 rate prior to 1990 for the 1956-1995 REP. The estimated REP collective dose was then divided by an estimate of the numbers ever exposed to ionising radiation during the REP. These estimates were obtained by multiplying the CIDI point estimates of IR exposed workers (see below) by the employment turnover factors in Table A1 and by the number of years in the REP (40 for the solid tumours).

For aircrew that are not covered by the CIDI data, an estimate of lifetime dose from Langner *et al.* (2004) was used. In a large seven country European cohort of airline pilots employed from the earliest days of air transport (1921, Finland to 1965, Italy) up to between 1994 and 1997, the mean total lifetime radiation dose per pilot for all pilots in the cohort was 15.3mSv, (median 10.7mSv, maximum 78.5mSv). The annual mean dose rate of all active pilots was 2.96 $\mu$ Sv per block hour flying time, for an average of 7,031 block hours. Pilots in the cohort were employed for an average 14.6 years. The lifetime dose estimate of 15.3mSv per worker is used to estimate ERR for aircrew.

ERR(a) was estimated for ages (a) that could be attained by workers in 2005 who had been exposed during the REP between the ages of 15 and 65 (an even distribution of ages from 15 to 65 in the exposed cohorts was assumed). ERR (all ages) was then obtained as the average across these ages.

Standard errors were not available from the UNSCEAR data so no confidence intervals are given.

For the present study the RR estimate is 1.005 for men and 1.021 for women for ionising radiation exposed workers (with an estimated average lifetime dose of 15.3mSv) and the same for aircrew (also with an estimated average lifetime dose of 15.3mSv).

**(b) Numbers exposed**

Data from the HSE's Central Index of Dose Information (HSE, 1998) indicates that there were 43,805 people exposed above 0.1mSv in GB in 1990. The data exclude aircrew. A breakdown by occupation is given in Table 40 below. Estimated numbers exposed over 0.1mSv are split between men and women from the proportion of men (93%) with recorded doses between 1997 and 2004. Estimates of numbers of aircraft flight deck officers and male travel and flight attendants estimated from the LFS for 1979, are also given in Table 40. CIDI data from 1990 and LFS data from 1979 are used as a best available point estimate for numbers exposed in the 'solid tumour' REP, 1956-1995.

For female air stewardesses, full data of numbers employed since 1958 was available from the British Airways Stewards and Stewardesses Union (for women only). Noting that in 2003 the number of women stewardesses employed by BA (11,479) was 48% of the LFS 'air travel assistants' total (23,890), and 55% of the CAA 'cabin attendants' total (20,761), doubling the BA numbers of new starters during the REP gives an appropriate estimate of stewardesses 'ever employed' in the period (13,902 in 1956-95). These 'ever exposed' numbers for air stewardesses are given in Table 40 and are used in the estimation of AF for this part of the exposed population (bypassing the usual turnover equation estimate).

**Table 40** Numbers of workers exposed to >0.1mSv ionising radiation in GB in 1990, from CIDI, numbers of aircrew in 1979, from LFS data, and air stewardesses from BA union data

	Industry/occupation	Numbers exposed >0.1 mSv			
		M	F	Total	%male
	<b>REP 1956-95</b>				
	<b>CIDI 1990</b>				
C-E	Nuclear Power	13414	1010	14424	93%
C-E	Nuclear Fuel Fabrication/ Reprocessing	7376	555	7931	93%
C-E	General Industry	7489	564	8053	93%
C-E	Industrial Radiography	2614	197	2811	93%
C-E	Non-coal Mining	264	20	284	93%
C-E	Radiation Protection	2407	181	2588	93%
C-E	Waste Treatment	1202	90	1292	93%
C-E	Nuclear Industry Misc.	683	51	734	93%
C-E	Other	4275	322	4597	93%
	<i>Sub-total</i>	<i>39724</i>	<i>2990</i>	<i>42714</i>	
G-Q	Medical/Dental	408	31	439	93%
G-Q	Transport	179	13	192	93%
G-Q	Academic	428	32	460	93%
	<i>Sub-total</i>	<i>1015</i>	<i>76</i>	<i>1091</i>	
	<b>CIDI Total &gt;0.1 mSv</b>	<b>40739</b>	<b>3066</b>	<b>43805</b>	
	<b>LFS 1979</b>				
G-Q	Aircraft Flight Deck Officers	6915	-	6915	
G-Q	Supervisors of Travel Stewards and Attendants	258			
G-Q	Travel Stewards and Attendants	6248			
	<b>BA stewards and stewardesses union data</b>				
	Air stewardesses, number employed 1956-1995		13,902		
	<b>Aircrew Total</b>	<b>13421</b>			

**(c) AF calculation**

For lung cancer related to exposure to ionising radiation the estimated total (male & female) attributable fraction is 0.01% (95%CI not available), which equates to 2 deaths and 2 registrations. The estimated AF for men is 0.006% resulting in 1 attributable death and 1 attributable registration; and for women is 0.004% resulting in 1 attributable death and 1 attributable registration (Table 41).



**Table 41** Summary results for occupational exposure to ionising radiation

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	UNSCEAR (2008)	H	C-E	1.005	39724	1.4	0.09	192147	0.0099	0.0000			1			1		
		H	G-Q	1.005	1015	0.9	0.11	3816	0.0002	0.0000			0			0		
		H	All		40739			195964	0.0101	0.0001			1			1		
		L	G-Q	1.005	13421	0.9	0.11	56071	0.0029	0.0000			0			0		
		L	All		13421			56071	0.0029	0.0000			0			0		
		All	All		54160			252035	0.0130	0.0001			1			1		
Women	UNSCEAR (2008)	H	C-E	1.021	2990	1.5	0.14	25154	0.0012	0.0000			0			0		
		H	G-Q	1.021	76	0.8	0.15	364	0.0000	0.0000			0			0		
		H	All		3066			25518	0.0012	0.0000			0			0		
		L (Aircrew)	G-Q	1.03	-			13902	0.0007	0.0000			0			0		
		L (Aircrew)	All					13902	0.0007	0.0000			0			0		
		All	All		3066			39420	0.0019	0.0000			1			1		

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### **3.15 LEAD**

#### **(a) Risk estimate**

As stated in Section 2 lead has been re-evaluated by a recent IARC Working Group to 2A carcinogen (IARC, 2006a). However, only one of the six available cohort studies showed a statistically significant two-fold excess of lung cancer among smelter workers, an excess that may have been caused by co-exposure to arsenic. A review of eight industry studies, mostly of smelter and battery workers (Steenland and Boffetta, 2000), indicated a RR of 1.30 (95%CI=1.15-1.46, 675 observed deaths) for lung cancer. Exclusion of one study with the highest RR where confounding with arsenic was thought to be an issue, gave a combined RR of 1.14 (95%CI=1.04-1.73). For the present study this has been used for the estimate for the higher exposed workers. Due to the absence of sufficient dose-response data the risk estimate for low exposure was based on a harmonic mean of the high/low ratios across all other cancer-exposure pairs in the overall project where data were available. As this was less than 1 the RR for low exposure has been set to 1.

#### **(b) Numbers exposed**

The number of workers possibly exposed to lead according to CAREX is given in Table 42. Two exposure categories have been considered: high and low. The higher exposed group is those CAREX SIC categories having members in the frequent or moderately frequent high exposure groups according to the NTP ROC Substance Profile (NTP, 2005). Other CAREX exposures are assumed to be at a background level. It has been assumed that workers exposed to lead in the CAREX numbers were split between men and women on the basis of employment in "blue collar" jobs from the 1991 Census. Numbers employed in 'Iron and steel basic industries' have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers.

**Table 42** Numbers of workers exposed to lead and lead compounds (inorganic) in British industries according to CAREX 1990-1993.

Industry	CAREX Data 1990-1993		
	Number Exposed	Number in Industry	Exposure Level
Crude petroleum and natural gas production	2867	53300	L
Metal ore mining	90	1225	H
Food manufacturing	567	414150	L
Beverage industries	102	88100	L
Tobacco manufacture	12	9950	L
Manufacture of textiles	169	182000	L
Manufacture of wearing apparel, except footwear	489	189500	L
Manufacture of leather and products of leather or of its substitutes	4	16825	L
Manufacture of wood and wood and cork products, except furniture	858	132975	L
Manufacture of paper and paper products	410	119050	L
Printing, publishing and allied industries	1048	354750	L
Manufacture of industrial chemicals	1756	130000	H
Manufacture of other chemical products	2714	175175	H
Petroleum refineries	210	18075	L
Manufacture of miscellaneous products of petroleum and coal	87	1125	L
Manufacture of rubber products	837	53025	L
Manufacture of plastic products nec	7586	136900	H
Manufacture of pottery, china and earthenware	9470	54450	L
Manufacture of glass and glass products	3477	43275	L
Manufacture of other non-metallic mineral products	2002	70875	L
Iron and steel basic industries	3714	48425	H
Non-ferrous metal basic industries	6200	79325	H
Manufacture of fabricated metal products, except machinery & equipment	13454	292200	L
Manufacture of machinery except electrical	24045	692275	L
Manufacture of electrical machinery, apparatus, appliances and supplies	7780	473750	H
Manufacture of transport equipment	15084	456900	L
Manufacture of instruments, photographic and optical goods	3406	86225	L
Other manufacturing industries	1387	59375	L
Electricity, gas and steam	2684	140975	L
Water works and supply	3833	45175	L
Construction	27338	1753450	H
Wholesale and retail trade and restaurants and hotels	9710	4459525	L
Land transport	1829	671050	L
Water transport	1840	68175	L
Air transport	2420	95700	L
Services allied to transport	755	180725	L
Communication	8506	459425	L
Public administration and defence	250	1557875	L
Sanitary and similar services	708	274225	L
Personal and household services	79714	686750	L
<b>Total</b>	<b>249,412*</b>	<b>14,826,250</b>	
<b>Main Industry Sector</b>		<b>% Male</b>	
Agriculture, hunting & forestry, fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	28,011	76%
	Low	84,617	76%
Construction	High	27,338	99%
	Low	0	
Service industries	High	0	
	Low	105,732	65%

\* includes workers in iron and steel basic industries (excluded from the analysis)

**(c) AF calculation**

For lung cancer related to exposure to lead and lead compounds the estimated total (male and female) attributable fraction is 0.11% (95%CI=0.00%-0.40%), which equates to 36 (95%CI=0-130) deaths and 41 (95%CI=0-149) registrations. The estimated AF for men is 0.16% (95%CI=0.00%-0.58%) resulting in 30 (95%CI=0-110) attributable deaths and 35 (95%CI=0-126) attributable registrations; and for women the AF is 0.04% (95%CI=0.00%-0.15%) resulting in 5 (95%CI=0-20), attributable deaths and 6 (95%CI=0-22) attributable registrations (Table 43).

**Table 43** Summary results for occupational exposure to inorganic lead

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Steenland & Boffetta, (2000)	H	C-E	1.14	20512	1.4	0.09	99216	0.0051	0.0007	0.0000	0.0028	14	0	53	16	0	62
		H	F	1.14	27065	1	0.12	122855	0.0063	0.0009	0.0000	0.0030	17	0	56	19	0	65
		H	All		47576			222071	0.0114	0.0016	0.0000	0.0058	30	0	110	35	0	126
		L	C-E	1	65105	1.4	0.09	314918	0.0162	0.0000	0.0000	0.0000	0	0	0	0	0	0
	L	G-Q	1	68726	0.9	0.11	258415	0.0133	0.0000	0.0000	0.0000	0	0	0	0	0	0	
	L	All		133831			573334	0.0296	0.0000	0.0000	0.0000	0	0	0	0	0	0	
		All	All		181408			795404	0.0410	0.0016	0.0000	0.0058	30	0	110	35	0	126
Women	Steenland & Boffetta, (2000)	H	C-E	1.14	6451	1.5	0.14	54273	0.0026	0.0004	0.0000	0.0014	5	0	20	6	0	22
		H	F	1.14	273	0.67	0.15	1096	0.0001	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H	All		6725			55369	0.0026	0.0004	0.0000	0.0015	5	0	20	6	0	22
		L	C-E	1	20560	1.5	0.14	172961	0.0082	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	37006	0.8	0.15	177200	0.0084	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		57566			350161	0.0167	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		64291			405530	0.0193	0.0004	0.0000	0.0015	5	0	20	6	0	22

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.16 MINERAL OILS

#### (a) Risk estimate

The evidence for an increased risk of lung cancer in workers exposed to mineral oils is not conclusive, for example studies of metalworkers have generally shown negative results, whereas increases have been observed in the majority of studies of workers in the printing industry (Tolbert, 1997) as seen below in the studies of newspaper pressmen:

Lynge <i>et al.</i> (1995)	SIR=2.0	95%CI=1.3-3.0
Leon <i>et al.</i> (1994)	SMR=1.8	95%CI=1.4-2.2
Paganini-Hill <i>et al.</i> (1980)	SMR=1.5	95%CI=0.9-2.2
Menck & Henderson (1976)	SMR=2.8	95%CI not reported
	SMR=1.0	95%CI not reported
Lloyd <i>et al.</i> (1977)	PMR=1.1	95%CI=NS
Malker & Gemne (1987)	SIR=1.8	95%CI=1.3-2.9

We have used the results from these seven studies to calculate an inverse variance weighted combined estimate of RR (random effects model; Q test indicated significant heterogeneity,  $Q=20.05$ ,  $p=0.0027$ ). The combined RR is 1.58 (95%CI=1.3-1.9), which is used for the calculation of attributable fraction for printers (indicated by 'P' in Table 44). This figure has been applied to women as well as men, all assumed to be exposed at the same level. Tolbert suggested the primary constituent that distinguishes newspaper printing ink from metalworking fluids is carbon black, which is known to be contaminated with BaP and other PAHs, plausible aetiologic agents for any association of printing ink with lung cancer.

An overall RR for lung cancer from exposure to mineral oils for other industries can be estimated using a weighted average across the case-control and population based studies from Tolbert's review excluding studies of the printing and newspaper industry. This gives an overall risk of 1.08 (95%CI=1.04-1.11). In the present study this has been used for the high exposure to MWF categories (H in Table 44). Due to the absence of sufficient dose-response data the risk estimate for low exposure was based on a harmonic mean of the high/low ratios across all other cancer-exposure pairs in the overall project where data were available. As this was less than 1 the RR for low exposure has been set to 1 (L in Table 44).

#### (b) Numbers exposed

The numbers of machinists exposed to mineral oils (metal working fluids) in Great Britain are shown in Table 44.

- 'Low' (L) exposure levels are indicated as such
- Printers are abbreviated as P.
- Exposure level (H) indicates jobs with known exposure to soluble MWF in large droplet form.

The jobs for printing were restricted to those thought to be exposed to printing inks. Motor mechanics, maintenance fitters (aircraft engines) and office machinery mechanics and their foremen would only be exposed dermally, and are therefore excluded.

**Table 44** Numbers of workers exposed to mineral oils according to LFS 1979

SIC code	Description	Male	Female	Total	Exposure Level
<b>LFS 1979</b>					
99.3	Foremen of Printing Machine Minders and Assistants	5318	472	5790	P
99.5	Foremen of Printers (So Described)	1584	236	1820	P
100.3	Printing Machine Minders and Assistants	42718	13194	55912	P
100.5	Printers (So Described)	49790	5312	55102	P
111.1	Foremen of Press and Machine Tool Setters	2164	-	2164	L
111.2	Foremen of other Centre Lathe Turners	736	-	736	L
111.3	Foremen of Machine Tool Setter Operators	581	-	581	L
111.4	Foremen of Machine Tool Operators	8947	252	9199	L
111.5	Foremen of Press Stamping and Automatic Machine Operators	1498	-	1498	L
111.6	Foremen of Metal Polishers	265	-	265	L
111.7	Foremen of Fettle Dressers	-	-	-	L
111.8	Foremen of Shot Blasters	-	-	-	L
112.1	Press and Machine Tool Setters	64157	740	64897	H
112.2	Other Centre Lathe Turners	49774	-	49774	H
112.3	Machine Tool Setter Operators	10818	232	11050	H
112.4	Machine Tool Operators	335097	50424	385521	H
113.1	Press Stamping and Automatic Machine Operators	34002	18281	52283	H
113.2	Metal Polishers	11112	1425	12537	L
113.3	Fettle Dressers	12391	1619	14010	L
114.1	Foremen of Toolmakers Tool Fitters Markers-Out	4319	-	4319	L
114.2	Foremen of Precision Instrument Makers and Repairers	969	-	969	L
114.3	Foremen of Watch and Chronometer Makers and Repairers	-	-	-	L
114.4	Foremen of Metal Working Production Fitters and Fitter/Machinists	27544	-	27544	L
114.5	Foremen of Motor Mechanics Auto Engineers	13825	-	13825	-
114.6	Foremen of Maintenance Fitters (Aircraft Engines)	522	-	522	-
114.7	Foremen of Office Machinery Mechanics	-	-	-	-
115.0	Toolmakers Tool Fitters Markers-Out	92886	510	93396	H
116.1	Precision Instrument Makers and Repairers	28071	1667	29738	L
116.2	Watch and Chronometer Makers and Repairers	6527	225	6752	L
117.0	Metal Working Production Fitters and Fitter/Machinists	546544	6933	553477	L
118.1	Motor Mechanics Auto Engineers	269925	1271	271196	-
118.2	Maintenance Fitters (Aircraft Engines)	3957	-	3957	-
119.0	Office Machinery Mechanics	11506	-	11506	-
131.8	Shot Blasters	6049	-	6049	L
160.5	Labourers and Other Unskilled Workers in Foundries in Engineering	15469	567	16036	L
160.6	Labourers and Other Unskilled Workers in Engineering and Allied Trades	21276	259	21535	L
<b>TOTAL excluding those dermally exposed only</b>		<b>1,380,606</b>	<b>102,348</b>	<b>1,482,954</b>	

**(c) AF calculation**

For lung cancer related to exposure to mineral oils the estimated total (male and female) attributable fraction is 1.25% (95%CI=0.44%-2.14%), which equates to 410 (95%CI=146-701) deaths and 470 (95%CI=167-804) registrations. The estimated AF for men is 1.83% (95%CI=0.63%-3.15%) resulting in 348 (95%CI=119-600) attributable deaths and 401 (95%CI=137-691) attributable registrations; and for women the AF is 0.45% (95%CI=0.19%-

0.73%) resulting in 61 (95%CI=27-100) attributable deaths and 69 (95%CI=30-113) attributable registrations (Table 45).



**Table 45** Summary results for occupational exposure to mineral oils

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Tolbert, (1997)	P	C-E	1.58	99410	1.4	0.09	343465	0.0177	0.0101	0.0049	0.0164	192	93	313	221	107	360
		P	All		99410			343465	0.0177	0.0101	0.0049	0.0164	192	93	313	221	107	360
		H	C-E	1.08	586734	1.4	0.09	2027188	0.1045	0.0082	0.0000	0.0200	156	0	381	180	0	439
		H	All		586734			2027188	0.1045	0.0082	0.0000	0.0200	156	0	381	180	0	439
		L	C-E	1	694462	1.4	0.09	2399393	0.1237	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		694462			2399393	0.1237	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		1380606			4770047	0.2459	0.0183	0.0063	0.0315	348	119	600	401	137	691
		Women	Tolbert, (1997)	P	C-E	1.58	19214	1.5	0.14	107760	0.0051	0.0030	0.0014	0.0048	41	20	66	46
		P	All		19214			107760	0.0051	0.0030	0.0014	0.0048	41	20	66	46	22	75
		H	C-E	1.08	70187	1.5	0.14	393639	0.0187	0.0015	0.0000	0.0037	21	0	51	23	0	57
		H	All		70187			393639	0.0187	0.0015	0.0000	0.0037	21	0	51	23	0	57
		L	C-E	1	12947	1.5	0.14	72612	0.0035	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		12947			72612	0.0035	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		102348			574012	0.0273	0.0045	0.0019	0.0073	61	27	100	69	30	113

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.17 NICKEL

#### (a) Risk estimate

Seilkop and Oller (2003) reviewed 25 epidemiological studies that had been conducted on workers employed in the production and use of nickel. In these studies it was clear that nearly all of the workers, particularly those in refineries, were exposed to several forms of nickel. However, the International Committee on Nickel Carcinogenesis in Man (ICNCM) (1990)(ICNCM, 1990) were able to divide the different nickel operations into “low” and “high” exposure groups, which corresponded reasonably well with “low” and “high” levels of lung cancer risk<sup>11</sup>. The “high” exposure, “high” risk nickel cohorts are confined to workers in refineries and historically have had the highest workplace exposures to nickel. In the sintering and calcining operations at refineries, including Clydach in Wales, sulphidic and oxidic nickel concentrations exceeded 10mgNi/m<sup>3</sup>. These operations are now obsolete. Electro-refining operations were estimated to produce soluble nickel concentrations that exceeded 1mgNi/m<sup>3</sup>. In all other workplaces, including mining and smelting, workers employed at hydrometallurgical refineries, at nickel alloy and stainless steel production facilities, as stainless steel welders, involved in nickel-cadmium electroplating and at a barrier production facility, exposures were low. Subsequently the risk of lung cancer was low, and although some studies of these industries found an increase in lung cancer these were attributed to other concomitant exposures including PAHs and asbestos.

The recent update by Sorahan and Williams (2005) of the Clydach refinery gave an SMR for lung cancer of 1.39 (95%CI=0.92-2.01) and will be applied in the present study to the Clydach refinery population only.

Seilkop and Oller (2003) extrapolated the lung cancer risk in high risk cohorts to low exposure cohorts. The weighted average of these SMRs (1.03, 95%CI=0.97-1.10) was used in the present study for all exposed workers apart from the nickel refineries at Clydach and those determined to have very low or negligible exposure (L in Table 46).

Those individuals determined to have very low or negligible (background (B) in Table 46) exposure will be assumed to have no excess risk of lung cancer (RR=1).

#### (b) Numbers exposed

Table 46 gives the numbers of workers exposed to nickel by industry according to CAREX for 1990-1993. The number of workers first employed in the period 1953-1992 with at least five years of employment at Clydach was 812 (Sorahan and Williams, 2005). This is the number of males considered to be ‘highly exposed’ and all were male. The numbers ever exposed for the calculation of AF for Clydach were 164, estimated from the first part of the turnover equation (equation (5.3) in the Methodology Technical Report) to account for survival to the target year (2005). It has been assumed however that other workers exposed to nickel in the CAREX numbers were split between men and women on the basis of employment in “blue collar” jobs from the 1991 Census. Numbers employed in ‘Iron and steel basic industries’ have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers.

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<sup>11</sup> See Seilkop and Oller (2003) for list of references

**Table 46** Numbers of workers exposed to nickel according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Metal ore mining	387	1225	L
Food manufacturing	1359	414150	B
Manufacture of paper and paper products	1126	119050	B
Printing, publishing and allied industries	13	354750	B
Manufacture of industrial chemicals	1408	130000	B
Manufacture of other chemical products	31	175175	B
Manufacture of pottery, china and earthenware	267	54450	B
Manufacture of glass and glass products	472	43275	B
Iron and steel basic industries	1658	48425	L
Non-ferrous metal basic industries	9388	79325	L
Manufacture of fabricated metal products, except machinery and equipment	27696	292200	L
Manufacture of machinery except electrical	25091	692275	B
Manufacture of electrical machinery, apparatus, appliances and supplies	960	473750	B
Manufacture of transport equipment	12901	456900	L
Manufacture of instruments, photographic and optical goods	524	86225	B
Other manufacturing industries	242	59375	B
Electricity, gas and steam	609	140975	B
Construction	448	1753450	B
Air transport	17	95700	B
Services allied to transport	24	180725	B
<b>Total</b>	<b>84621*</b>	<b>5,651,400</b>	
<b>Main Industry Sector</b>		<b>Male %</b>	
Agriculture, hunting and forestry; fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	0	
	Low	50372	76%
	Negligible	32102	76%
Construction	High	0	
	Low	0	
	Negligible	448	99%
Service industries	High	0	
	Low	0	
	Negligible	41	65%

\* includes workers in iron and steel basic industries (excluded from the analysis)

**(c) AF calculation**

For lung cancer related to exposure to nickel the estimated total (male and female) attributable fraction is 0.02% (95%CI=0.00%-0.08%), which equates to 8 deaths (95%CI=0-25), and 9 (95%CI=0-29) registrations. The estimated AF for men is 0.03% (95%CI=0.00%-0.10%) resulting in 6 (95%CI=0-19) attributable deaths and 6 (95%CI=0-22) attributable registrations; and for women the AF is 0.01% (95%CI=0.00%-0.05%) resulting in 2 (95%CI=0-6) attributable deaths and 2 (95%CI=0-7) attributable registrations (Table 47).

**Table 47** Summary results for occupational exposure to nickel

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
<b>Men</b>		B	C-E	1	24398	1.4	0.09	118012	0.0061	0.0000	0.0000	0.0000	0	0	0	0	0	0
		B	F	1	444	1	0.12	2013	0.0001	0.0000	0.0000	0.0000	0	0	0	0	0	0
		B	G-Q	1	27	0.9	0.11	100	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		B	All		24868			120126	0.0062	0.0000	0.0000	0.0000	0	0	0	0	0	0
	Sorahan and Williams (2005)	H	C-E	1.39	812	1.4	0.09	164	0.0000	0.0000	0.0000	0.0000	0	0	3	0	0	3
	H	All		812			164	0.0000	0.0000	0.0000	0.0000	0	0	3	0	0	3	
Seilkop and Oller (2003)	L	C-E	1.03	38368	1.4	0.09	185587	0.0096	0.0003	0.0000	0.0009	5	0	18	6	0	20	
	L	All		38368			185587	0.0096	0.0003	0.0000	0.0009	5	0	18	6	0	20	
	All	All		64048			305877	0.0158	0.0003	0.0000	0.0010	6	0	19	6	0	22	
	<b>Women</b>	B	C-E	1	7704	1.5	0.14	64815	0.0031	0.0000	0.0000	0.0000	0	0	0	0	0	0
	B	F	1	4	0.67	0.15	18	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	
	B	G-Q	1	14	0.8	0.15	69	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0	
	B	All		7723			64902	0.0031	0.0000	0.0000	0.0000	0	0	0	0	0	0	
Seilkop and Oller (2003)	L	C-E	1.03	12004	1.5	0.14	100987	0.0048	0.0001	0.0000	0.0005	2	0	6	2	0	7	
	L	All		12004			100987	0.0048	0.0001	0.0000	0.0005	2	0	6	2	0	7	
	All	All		19727			165888	0.0079	0.0001	0.0000	0.0005	2	0	6	2	0	7	

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.18 POLYCYCLIC AROMATIC HYDROCARBON

#### (a) Risk estimate

The risk estimate used is an adaptation of the Unit Relative Risk (URR) estimate for all the industrial cohorts from the paper by Armstrong *et al.* (2004) meta-analysis, adjusted for smoking. A 20 year exposed working lifetime is assumed and the RR is given by ((URR) to the power of  $(x * 20/100)$ ) where x is the mean BaP level (e.g. 8 hour time weighted average (TWA)) in  $\mu\text{g} / \text{m}^3$  for the exposed. This is 1.31 (95%CI=1.16–1.48), mean RR at  $100\mu\text{g}/\text{m}^3$  BaP years.

Unwin *et al.* (2006) gives an indication from airborne monitoring of PAHs in an HSE commissioned cross-industry occupational hygiene survey, of the 8 h TWA levels of BaP in a range of workplaces. 8 h TWA BaP levels ranged from  $<0.01$  to  $6.21\mu\text{g}/\text{m}^3$ , with 50% of the samples below  $0.01\mu\text{g}/\text{m}^3$ , 90% below  $0.75\mu\text{g}/\text{m}^3$ , and 95% below  $2.0\mu\text{g}/\text{m}^3$ . For the present study the above calculation was used to derive a RR estimate at the mean (class mid-point) exposure levels give the following:

8 h TWA category ( $\mu\text{g}/\text{m}^3$ )	<0.01	0.01 - <0.75	0.75 - <2.0	2.0+
Mid-point BaP level ( $\mu\text{g}/\text{m}^3$ )	0.005	0.38	1.375	4.105
RR estimate	1.00	1.02	1.08	1.25

The low exposed were assumed to have a RR=1.0, corresponding to  $<0.01\mu\text{g}/\text{m}^3$  BaP 8 h TWA.

#### (b) Numbers exposed

Table 48 gives the numbers of workers exposed to PAHs by industry according to CAREX for 1990-1993. Below is an estimate of numbers exposed in each BaP level category, in the mining and manufacturing sectors (the high exposed group), based on the proportions in the different exposure categories from Unwin *et al.* (2006). All the CAREX exposed in this group are assumed to be men. The low exposed are split between men and women on the basis of estimated numbers of men and women employed in construction and the service sector from the 1991 Census.

Numbers employed in 'iron and steel basic industries have been excluded from the calculation to avoid double-counting their risk with 'steel foundry workers'.

**Table 48** Numbers of workers exposed to polycyclic aromatic hydrocarbons according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		Exposure Level
	Number Exposed	Number in Industry	
Crude petroleum and natural gas production	888	53300	L
Metal ore mining	103	1225	L
Other mining	217	28150	L
Food manufacturing	970	414150	L
Tobacco manufacture	102	9950	L
Manufacture of wearing apparel, except footwear	8444	189500	L
Manufacture of leather and products of leather or of its substitutes	214	16825	L
Manufacture of footwear	130	38500	L
Manufacture of wood and wood and cork products, except furniture	515	132975	L
Manufacture of paper and paper products	289	119050	L
Printing, publishing and allied industries	105	354750	L
Manufacture of industrial chemicals	1006	130000	H
Petroleum refineries	536	18075	L
Manufacture of miscellaneous products of petroleum and coal	82	1125	H
Manufacture of rubber products	3848	53025	L
Manufacture of pottery, china and earthenware	1362	54450	L
Manufacture of glass and glass products	818	43275	L
Manufacture of other non-metallic mineral products	2073	70875	H
Iron and steel basic industries	4913	48425	H
Non-ferrous metal basic industries	1626	79325	H
Manufacture of fabricated metal products, except machinery and equipment	6108	292200	L
Manufacture of machinery except electrical	4106	692275	L
Manufacture of transport equipment	9292	456900	L
Electricity, gas and steam	4996	140975	L
Construction	4511	1753450	L
Wholesale and retail trade and restaurants and hotels	4855	4459525	L
Land transport	9348	671050	L
Water transport	171	68175	L
Services allied to transport	692	180725	L
Public administration and defence	250	1557875	L
Sanitary and similar services	9442	274225	L
Personal and household services	24273	686750	L
<b>Total</b>	<b>106285*</b>	<b>13,091,075</b>	
<b>Main Industry Sector</b>		<b>% Male</b>	
Agriculture, hunting and forestry; fishing	High	0	
	Low	0	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High	<b>4787</b>	76%
	Low	<b>43043</b>	
Construction	High	<b>0</b>	
	Low	<b>4511</b>	99%
Service industries	High	<b>0</b>	
	Low	<b>49031</b>	65%

\* includes workers in iron and steel basic industries (excluded from the analysis)

The total number exposed at the higher level given in Table 48 has been split assuming the proportions given in line 2 below and the relevant RRs for these groups then applied.

<b>Exposure levels assumed for the 'higher exposure' group</b>				
<b>8 h TWA category (<math>\mu\text{g}/\text{m}^3</math>)</b>	<b>&lt;0.01</b>	<b>0.01 - &lt;0.75</b>	<b>0.75 - &lt;2.0</b>	<b>2.0+</b>
Proportion exposed	50%	40%	5%	5%
CAREX numbers exposed (men)	1819	1455	182	182
CAREX numbers exposed (women)	574	460	57	57
RR estimate	1.00	1.02	1.08	1.25

**(c) AF calculation**

The AF related to exposure to PAHs was obtained by calculating a separate AF for each 8 hour TWA category from the estimated RR and numbers exposed given above, and summing these across exposure levels. Although 2% of the men and 0.4% of women are estimated to have been exposed to PAHs at some level between 1955 and 1994, for lung cancer, overall exposure to PAHs was estimated

For lung cancer related to exposure to PAHs the estimated total (male and female) attributable fraction is 0.003% (95%CI=0.001%-0.003%), which equates to 1 (95%CI=0-1) death and 1 (95%CI=0-1) registration. The estimated AF for men is 0.002% (95%CI=0.002%-0.004%) resulting in 1 (95%CI=0-1) attributable death and 1 (95%CI=0-1) attributable registration; and for women the AF is 0.001% (95%CI=0.001%-0.002%) resulting in 0 (95%CI=0-0) attributable deaths and 0 (95%CI=0-0) attributable registrations (Table 49).

**Table 49** Summary results for occupational exposure to PAHs

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
<b>Men</b>	Armstrong <i>et al.</i> (2004)	H1	C-E	1.25	182	1.4	0.09	880	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H1	All		182			880	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H2	C-E	1.08	182	1.4	0.09	880	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H2	All		182			880	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H3	C-E	1.02	1455	1.4	0.09	7039	0.0004	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H3	All		1455			7039	0.0004	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H4	C-E	1.0003	1819	1.4	0.09	8799	0.0005	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H4	All		1819			8799	0.0005	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	C-E	1.0003	32783	1.4	0.09	158574	0.0082	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	F	1.0003	4466	1	0.12	20272	0.0010	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1.0003	31870	0.9	0.11	119835	0.0062	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		69119			298680	0.0154	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		72757			316278	0.0163	0.0000	0.0000	0.0000	1	0	1	1	0	1
	<b>Women</b>	Armstrong <i>et al.</i> (2004)	H1	C-E	1.25	57	1.5	0.14	483	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0
H1			All		57			483	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H2	C-E	1.08	57	1.5	0.14	483	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H2	All		57			483	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H3	C-E	1.02	460	1.5	0.14	3866	0.0002	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H3	All		460			3866	0.0002	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H4	C-E	1.0003	574	1.5	0.14	4833	0.0002	0.0000	0.0000	0.0000	0	0	0	0	0	0
		H4	All		574			4833	0.0002	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	C-E	1.0003	10260	1.5	0.14	86313	0.0041	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	F	1.0003	45	0.67	0.15	181	0.0000	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1.0003	17161	0.8	0.15	82173	0.0039	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		27466			168667	0.0080	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		28615			178332	0.0085	0.0000	0.0000	0.0000	0	0	0	0	0	0



1. Specific scenario or main industry code –see – (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### **3.19 RADON**

#### **(a) Risk estimate**

High levels of radon in the workplace occur in similar areas to those of concern in residential dwellings in the UK (NRPB/M386: Regional variations in the potential for occupational exposures to radon, NRPB). The counties most seriously affected by radon are Cornwall and Devon. However, surveys of radon levels indicate substantially increased radon levels in Northamptonshire and parts of Derbyshire, Somerset, Wales, Grampian and the Highlands of Scotland. Elevated levels have also been found in small pockets in other areas. These areas have been defined by Government as Radon Affected Areas. On the basis of these levels and the Committee on Health Risks of Exposure to Radon, Biological Effects of Ionizing Radiation, BEIR VI models (BEIRVI, 1998), the UK Health Protection Agency (HPA), formerly the National Radiological Protection Board (NRPB), estimate that approximately 2,000 cases per year are attributable to exposure to radon in the home and at work (NRPB, 2000). The HPA estimates that approximately 93 to 276 of the 2,000 deaths result from radon exposure in the workplace (personal communication; see Annex 1).

#### **(b) Numbers exposed**

Table 50 gives the numbers of workers exposed to radon by industry according to CAREX for 1990-1993. All are assumed to be exposed at the same level. These data are not used in the calculation of AF given below, but are used to allocate total occupational lung cancers due to radon exposure between industries.

**Table 50** Numbers of workers exposed to radon according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993	
	Number Exposed	Number in Industry
Agriculture and hunting	2016	419825
Forestry and logging	39	14500
Metal ore mining	193	1225
Food manufacturing	11927	414150
Beverage industries	2643	88100
Tobacco manufacture	301	9950
Manufacture of textiles	5470	182000
Manufacture of wearing apparel, except footwear	5519	189500
Manufacture of leather and products of leather or of its substitutes	508	16825
Manufacture of footwear	1163	38500
Manufacture of wood and wood and cork products, except furniture	3149	132975
Manufacture of furniture and fixture, except primary of metal	4158	144325
Manufacture of paper and paper products	3179	119050
Printing, publishing and allied industries	9044	354750
Manufacture of industrial chemicals	3510	130000
Manufacture of other chemical products	4936	175175
Petroleum refineries	382	18075
Manufacture of miscellaneous products of petroleum and coal	33	1125
Manufacture of rubber products	1591	53025
Manufacture of plastic products nec	3738	136900
Manufacture of pottery, china and earthenware	1278	54450
Manufacture of glass and glass products	1027	43275
Manufacture of other non-metallic mineral products	1678	70875
Iron and steel basic industries	1291	48425
Non-ferrous metal basic industries	2122	79325
Manufacture of fabricated metal products, except machinery and equipment	8063	292200
Manufacture of machinery except electrical	18491	692275
Manufacture of electrical machinery, apparatus, appliances and supplies	13930	473750
Manufacture of transport equipment	10858	456900
Manufacture of instruments, photographic and optical goods	2579	86225
Other manufacturing industries	1781	59375
Electricity, gas and steam	3258	140975
Water works and supply	550	45175
Construction	21314	1753450
Wholesale and retail trade and restaurants and hotels	124535	4459525
Land transport	11466	671050
Water transport	1638	68175
Air transport	2388	95700
Services allied to transport	3473	180725
Communication	8000	459425
Financing, insurance, real estate and business services	78320	2830800
Public administration and defence	36732	1557875
Sanitary and similar services	6004	274225
Education services	41051	1455875
Research and scientific institutes	2297	91100
Medical, dental, other health and veterinary services	41952	1435675
Welfare institutions	17222	741375
Business, professional and other organisation	3394	133075
Recreational and cultural services	12833	534600
Personal and household services	18701	686750
<b>Total</b>	<b>561725</b>	<b>22,612,600</b>

**(c) AF calculation**

The AF related to exposure to radon was calculated directly from the upper and lower estimates of attributable numbers suggested by the NRPB (93 and 276). Assuming men and women are equally affected, the AF for both is therefore between 0.28% and 0.84%, estimated by dividing these lower and upper limits by total lung cancer deaths in ages 25+ in 2005 (32,798). A mid-point estimate between these two figures (0.56%) has been used to calculate radon's contribution to overall lung cancer AF for men and for women. Total attributable deaths and registrations are allocated between industries in proportion to numbers ever exposed in the risk exposure period, with industry AFs based on attributable deaths (Table 67).

For lung cancer related to exposure to radon the estimated total (male and female) attributable fraction is 0.56% (95%CI=0.28%-0.84%), which equates to 184 (95%CI=92-276) deaths and 209 (95%CI=105-314) registrations. The estimated AF for men is 0.56% (95%CI=0.28%-0.84%) resulting in 107 (95%CI=53-160) attributable deaths and 123 (95%CI= 61-184) registrations; and for women the AF is 0.56% (95%CI=0.28%-0.84%) resulting in 77 (95%CI=39-116) deaths and 87 (95%CI=43-130) registrations. Full details of the calculation of attributable numbers for radon are given in Annex 1.

### 3.20 STRONG INORGANIC ACID MISTS CONTAINING SULPHURIC ACID

#### (a) Risk estimate

A population-based case-control study in Canada (Siemiatycki, 1991) and a cohort study of US male workers in pickling operations in the steel industry (Steenland and Beaumont, 1989) found an excess of lung cancer, even after adjusting for smoking and other potential confounding variables (smoking adjusted SMR for lung cancer for the whole cohort = 136, 95%CI=97–184), rising to 150 (95%CI=105–207) for more than 20 years since first exposure. A review of the literature on the relationship between mists containing sulphuric acid and lung cancer, concluded that there was little evidence in support of a causal relationship (Sathiakumar *et al*, 1997); with the exception of the paper by Steenland and Beaumont, no studies were considered in this review to be of sufficient quality to provide evidence, in terms of controlling for other potential carcinogenic exposures and confounding with smoking and socio-economic status. A UK study of workers exposed to chromic acid mist did show an excess lung cancer but these workers will be considered under chromium (Sorahan *et al*, 1998). In the present study the RR used for the high exposed workers is that of Steenland and Beaumont (1989) (RR=1.36, 95%CI=0.97-1.84). Coggon *et al*. (1996) found a RR of 0.98 in a study of lead battery workers; a RR of 1.0 is thus used for the low exposed group.

#### (b) Numbers exposed

The exposed to acid mists according to CAREX are given in Table 51. For this agent, the exposed numbers have been divided between men and women on the assumption that the CAREX exposed numbers were “blue-collar” workers (SOC Major Groups 5, 8 and 9) with low exposure level in the service industries (SIC Major Industry Sector G-Q). It has also been assumed that workers in the SIC Major Industry Sector C-E were only exposed at high exposure level, apart from petroleum production and pottery, china and earthenware. . Numbers employed in ‘Iron and steel basic industries’ have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers.

**Table 51** Numbers of workers exposed to strong acid mists according to CAREX in 1990-1993

Industry	CAREX Data 1990-1993		
	Number Exposed	Number in Industry	Exposure level
Crude petroleum and natural gas production	1429	53300	L
Manufacture of leather and products of leather or of its substitutes	760	16825	H
Manufacture of paper and paper products	2994	119050	H
Manufacture of industrial chemicals	5186	130000	H
Manufacture of other chemical products	6200	175175	H
Manufacture of pottery, china and earthenware	14	54450	L
Iron and steel basic industries	2378	48425	H
Non-ferrous metal basic industries	4293	79325	H
Manufacture of fabricated metal products, except machinery and equipment	5502	292200	H
Manufacture of machinery except electrical	3990	692275	H
Manufacture of electrical machinery, apparatus, appliances and supplies	4766	473750	H
Manufacture of transport equipment	3690	456900	H
Air transport	1131	95700	L
<b>Total</b>	<b>42333*</b>	<b>2,687,375</b>	
		<b>% Male</b>	
Mining/quarrying, electricity/gas/steam, manufacturing industry	High Low	39759 1443	76%
Service industries	Low	1131	65%

\* includes workers in iron and steel basic industries (excluded from the analysis)

**(c) AF calculation**

For lung cancer related to exposure to strong acid mists the estimated total (male and female) attributable fraction is 0.20% (95%CI=0.00%-0.55%), which equates to 67 (95%CI=0-181) deaths and 76 (95%CI=0-207) registrations. The estimated AF for men is 0.24% (95%CI=0.00%-0.64%) resulting in 45 (95%CI=0-123) attributable deaths and 52 (95%CI=0-141) attributable registrations; and for women the AF is 0.16% (95%CI=0.00%-0.42%) resulting in 21 (95%CI=0-58) attributable deaths and 24 (95%CI=0-66) attributable registrations (Table 52)

**Table 52** Summary results for occupational exposure to strong inorganic acid mists

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Steenland and Beaumont (1989)	H	C-E	1.36	26541	1.4	0.09	128378	0.0066	0.0024	0.0000	0.0064	45	0	123	52	0	141
		H	All		26541			128378	0.0066	0.0024	0.0000	0.0064	45	0	123	52	0	141
	Coggon <i>et al.</i> (1996)	L	C-E	1	1025	1.4	0.09	4956	0.0003	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	735	0.9	0.11	2764	0.0001	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		1760			7720	0.0004	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		28300			136098	0.0070	0.0024	0.0000	0.0064	45	0	123	52	0	141
Women	Steenland and Beaumont (1989)	H	C-E	1.36	10840	1.5	0.14	91197	0.0043	0.0016	0.0000	0.0042	21	0	58	24	0	66
		H	All		10840			91197	0.0043	0.0016	0.0000	0.0042	21	0	58	24	0	66
	Coggon <i>et al.</i> (1996)	L	C-E	1	418	1.5	0.14	3520	0.0002	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	G-Q	1	396	0.8	0.15	1895	0.0001	0.0000	0.0000	0.0000	0	0	0	0	0	0
		L	All		814			5416	0.0003	0.0000	0.0000	0.0000	0	0	0	0	0	0
		All	All		11655			96613	0.0046	0.0016	0.0000	0.0042	21	0	58	24	0	66

1. Specific scenario or main industry code -- (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.21 TALC CONTAINING ASBESTIFORM FIBRE

#### (a) Risk estimate

IARC (1987) concluded that there was inadequate evidence for the carcinogenicity to humans of talc not containing asbestiform fibres but there was sufficient evidence for talc containing the fibres. A recent review of the epidemiological evidence concurred with these statements finding no excess lung cancer mortality among talc millers exposed to high levels in the absences of other potential carcinogens, although excesses were seen in miners also exposed to quartz and/or radon and in other industrial settings (Wild, 2006). As a consequence talc will not be considered in the AF calculation for lung cancer.

#### (b) Numbers exposed

In GB approximately 5,000 tonnes are extracted every year. However, the country imports substantially more than this; this is unlikely to contain asbestos fibres. The number exposed in the UK is negligible.

#### (c) AF calculation

The AF calculation is thus omitted.

### 3.22 TCDD (2,3,7,8-TETRACHLORODIBENZO-PARA-DIOXIN)

#### (a) Risk estimate

Workers involved in the manufacture of pesticides may be exposed to TCDD (dioxins) contaminated chemicals as shown in a number of studies reviewed. Jones *et al.* (2009) have carried out a meta-analysis of a large number of studies from around the world and observed an excess risk of 1.22 (J in Table 53) (95%CI=1.05-1.41). In the present study this estimate will be used for manufacturers of formulated pesticides. Workers in agricultural occupations (farmers, etc.) would be involved in the spraying of pesticides that may be contaminated with TCDD, but as indicated previously would be exposed to lower levels. The risk estimate from Kogevinas *et al.* (1997) for sprayers, a large study of workers exposed to TCDD, will in this study be applied to workers in agriculture, horticulture, forestry and gardening (SMR=1.03, 95%CI=0.78-1.34) (K in Table 53).

For workers in pulp manufacture, an international collaborative study of 98665 workers employed between 1920 and 1996 in 11 countries, including Japan, New Zealand, United States, and Europe (8), found an overall risk for lung cancer of 1.04 (M in Table 53) (95%CI=0.96-1.13) (McLean *et al.*, 2006). The study included one of 4242 Scottish paper mill workers (Coggon *et al.*, 1997) that had observed 66 lung cancer cases between 1955 and 1994 (SMR=0.64, 95%CI=0.50-0.81). In this study for this group a RR of 1.04 will be used (M in Table 53).

Sweetman *et al.* (2004) and Eduljee and Dyke (1996) identified a number of work sites in the UK where occupational exposure to dioxins could occur. The sites with possibly the highest exposures, greater than in pesticide production, included metal recycling, ferrous metal production, zinc smelting, cement manufacture, municipal waste incinerators, coal power stations and workers on landfill site. The lung cancer risk in workers at these sites due to dioxin exposure is unknown.

IARC has established a register of workers exposed to phenoxy-acid herbicides and chlorophenols, substances that known to be contaminated with dioxins (especially TCDD) and furans (Kogevinas *et al.*, 1997). The risk estimate of 1.12 (W) (95%CI=0.98-1.28) will be used for industries where exposure may occur but levels of exposure are unknown (L in Table 53). The risk estimate from the Kogevinas study was chosen because it studied over 21,000 workers and observed 225 deaths from lung cancer among exposed workers.



**(b) Numbers exposed**

Table 53 gives the numbers of workers possibly exposed to dioxins in the production of pesticides, pulp manufacture and the other industries listed above according to the LFS for 1979 and the Census of Employment for 1981. A screening of a range of industrial processes operating in the UK for the potential to release dioxins short-listed 23 for consideration as potential emitters (Eduljee and Dyke, 1996). They include the combustion of coal (industrial/commercial, power generation), waste oil, municipal waste, wood, straw, tyres, landfill gas, chemical waste, clinical waste and sewage sludge. Other processes included industries involved in treated wood, gas production, sinter plants iron and steel, non-ferrous metals, manufacture of cement, lime, glass and ceramics, halogenated chemicals, carbon regeneration, asphalt mixing and PCP in timber processes, and pesticide production. According to this study pesticide production had an emission factor of 0.01-0.025  $\mu\text{g I-TEQ}$  of dioxin per tonne of product produced. They estimated that about 12,950 tonnes of product were produced in a year, which equated to between 130 and 325  $\mu\text{g I-TEQ}$  of dioxin. On the basis of emission factors from the study by Eduljee and Dyke (1996) the occupations with the potential for exposure to dioxins are given in the lower half of Table 53. Numbers employed in 'Iron and steel basic industries' have been excluded from the total of exposed numbers to avoid double counting with steel foundry workers.

**Table 53** Numbers of workers in different industries with potential for exposure to pesticides in Data from LFS 1979 and CoE 1981

SOC/ SIC Code	Job Title	Numbers employed			Risk estimate
		Men	Women	Total	
<b>LFS 1979</b>					
40.0	Farmers, horticulturalists, farm managers	208289	17956	226245	K
76.1	Farm Foremen	6702	236	6938	K
76.2	Horticultural Foreman	999		999	K
76.3	Foremen of Gardeners & Groundsmen	8177		8177	K
76.4	Agricultural Machinery Foremen			0	K
76.5	Forestry Foremen	1919		1919	K
76.6	Other Foremen in Farming and Related	759		759	K
77.0	Farm Workers	135216	29392	164608	K
78.1	Horticultural Workers	13130	6349	19479	K
78.2	Gardeners Groundsmen	103171	3535	106706	K
79.0	Agricultural Machinery Drivers Operators	15168	269	15437	K
80.0	Forestry Workers	9474		9474	K
83.0	All Other in Farming and Related	12986	8975	21961	K
	<b>Total A-B</b>	<b>515990</b>	<b>66712</b>	<b>582702</b>	K
<b>CoE 1981</b>					
2568	Formulated pesticides	1040	664	1704	J
4710	Paper and Pulp manufacture	36664	7764	44428	M
4610	Wood sawmill planning impregnation	21080	3317	24397	L
2512	Organic chemical manufacture	10656	2289	12945	L
2471	Flat glass manufacture	13237	3125	16362	L
2478	Glass containers	11880	1992	13872	L
2479	Other glass products	20227	7606	27833	L
2481	Refractory goods	10957	1598	12555	L
2489	Ceramic goods	26811	20534	47345	L
2420	Cement, lime, & plaster manufacture	14006	1682	15688	L
2210	Iron & steel industry	113897	20534	124608	L
2220	Steel tubes	28372	4454	32826	L
2234	Steel wire & wire products	19633	4949	24582	L
2235	Other drawing cold rolling forming of steel	5188	639	5827	L
2245	Aluminium & aluminium alloys	26979	4697	31676	L
2246	Copper, brass & other copper alloys	22870	4743	27613	L
2247	Other non-ferrous metals & their alloys	16498	3267	19765	L
<b>LFS 1979</b>					
57.3	Scrap & General Dealers Rag/Bone Merchants	9152	463	9615	L
	<b>Main Industry Sector</b>				
	Agriculture, hunting and forestry; fishing	K	515990	66712	582702
	Mining/quarrying, electricity/gas/steam, manufacturing industry	J M L*	1040 36664 248394	664 7764 64892	1704 44428 313286
	Construction				0
	Service industries	W	9152	463	9615

\*excludes workers in iron and steel basic industries

### (c) AF calculation

For lung cancer related to exposure to TCDD the estimated total (male and female) attributable fraction is 0.57% (95%CI=0.00%-1.49%), which equates to 187 (95%CI=0-488) deaths and 215 (95%CI=0-559) registrations. The estimated AF for men is 0.80% (95%CI=0.00%-2.12%) resulting in 152 (95%CI=0-405) attributable deaths and 175 (95%CI=0-46) attributable registrations; and for women the AF is 0.26% (95%CI=0.00%-0.60%) resulting in 36 (95%CI=0-83) attributable deaths and 40 (95%CI=0-93) attributable registrations (Table 54).

**Table 54** Summary results for occupational exposure to TCDD

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Kogevinas <i>et al.</i> (1997)	K	A-B	1.03	515990	1	0.07	1409785	0.0727	0.0022	0.0000	0.0135	41	0	257	47	0	296
		K	All		515990			1409785	0.0727	0.0022	0.0000	0.0135	41	0	257	47	0	296
	Jones <i>et al.</i> (2009)	J	C-E	1.22	1040	1.4	0.09	3593	0.0002	0.0000	0.0000	0.0001	1	0	1	1	0	2
		J	All		1040			3593	0.0002	0.0000	0.0000	0.0001	1	0	1	1	0	2
	McLean <i>et a.</i> (2006)	M	C-E	1.04	36664	1.4	0.09	126676	0.0065	0.0003	0.0000	0.0005	5	0	10	6	1	11
		M	All		36664			126676	0.0065	0.0003	0.0000	0.0005	5	0	10	6	1	11
	Kogevinas <i>et al.</i> (1997)	L	C-E	1.12	248394	1.4	0.09	858211	0.0442	0.0053	0.0000	0.0122	100	0	233	115	0	268
		L	G-Q	1.12	9152	0.9	0.11	38236	0.0020	0.0002	0.0000	0.0005	4	0	10	5	0	12
		L	All		257546			896447	0.0462	0.0055	0.0000	0.0128	105	0	243	121	0	280
		All	All		811240			2436500	0.1256	0.0080	0.0000	0.0212	152	0	405	175	0	466
Women	Kogevinas <i>et al.</i> (1997)	K	A-B	1.03	66712	0.75	0.1	273532	0.0130	0.0004	0.0000	0.0025	5	0	34	6	0	38
		K	All		66712			273532	0.0130	0.0004	0.0000	0.0025	5	0	34	6	0	38
	Jones <i>et al.</i> (2009)	J	C-E	1.22	664	1.5	0.14	3724	0.0002	0.0000	0.0000	0.0001	1	0	1	1	0	1
		J	All		664			3724	0.0002	0.0000	0.0000	0.0001	1	0	1	1	0	1
	McLean <i>et al.</i> (2006)	M	C-E	1.04	7764	1.5	0.14	43544	0.0021	0.0001	0.0000	0.0002	1	0	2	1	0	2
		M	All		7764			43544	0.0021	0.0001	0.0000	0.0002	1	0	2	1	0	2
	Kogevinas <i>et al.</i> (1997)	L	C-E	1.12	64892	1.5	0.14	363943	0.0173	0.0021	0.0000	0.0048	29	0	67	32	0	75
		L	G-Q	1.12	463	0.8	0.15	2771	0.0001	0.0000	0.0000	0.0000	0	0	1	0	0	1
		L	All		65355			366714	0.0175	0.0021	0.0000	0.0049	29	0	67	32	0	75
		All	All		140495			687514	0.0327	0.0026	0.0000	0.0060	36	0	83	40	0	93

1. Specific scenario or main industry code – (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### **3.23 HEMATITE MINING (UNDERGROUND), WITH EXPOSURE TO RADON**

#### **(a) Risk estimate**

The risk of lung cancer in underground haematite miners would be similar to that of underground tin miners. Any risk of radon exposure now is controlled by mine ventilation.

#### **(b) Numbers exposed**

The number of workers involved in iron ore mining is very small. The LFS surveys of 2000 and 2003 indicated there were 173 and 299 people employed, respectively

#### **(c) AF calculation**

The AF calculation will not be undertaken because of the small numbers involved

### **3.24 TIN MINERS (EXPOSURE TO RADON)**

#### **(a) Risk estimate**

Underground miners, notably tin miners in Cornwall, are known to be at high risk of exposure to radon. The SMR for lung cancer shows a consistent relationship with duration of underground exposure, rising from 0.83 (O/E – 8/9.6) for surface workers to 4.47 (O/E = 15/3.4) for workers with more than 30 years underground exposure (Hodgson and Jones, 1990). In the present study an overall SMR for the underground workers of 1.83 (95%CI=1.48-2.28) was estimated for the period of the study, based on 82 lung cancer deaths. However 166 lung cancer deaths were recorded between 1951 and 1999 in this cohort, of which 91 occurred from 1986-1999. Adding another 13 person years at risk (PYAR) to the study (1987-1999), as  $13 \times 2509$ , multiplied by the population lung cancer rate to estimate the expected number of lung cancer deaths up to 1999, gives an approximate overall RR of 2.54 (95%CI=2.18-2.96) for lung cancer, which was the RR used for this study.

#### **(b) Numbers exposed**

2,535 tin miners, 2,059 working underground, representing a complete cohort of those employed since 1941 in the two Cornish mines that survived through to 1984 were included in the above study, and probably represent the total of exposed workers in this industry during the risk exposure period. The numbers ever exposed for the calculation of AF were 416, estimated from the first part of the turnover equation (equation (3) in the Statistical Appendix) to account for survival to the target year (2005). Lung cancer due to work underground in a tin mine is a prescribed disease. Between 1990 and 2001 there were 21 recorded cases of prescribed disease D10, most of which were likely to have been in ex tin miners, an average of nearly 2 a year in this period. Although there is an overlap with exposure to radon that has been estimated elsewhere, this estimate is for a very particular group of high exposed workers whereas the overall radon estimate was based on average concentrations in the home extended to workplace exposures across the country. The separate AF for tin miners is therefore retained.

#### **(c) AF calculation**

Using the overall RR of 2.54 (95%CI=2.18-2.96) with the added person years at risk results in an estimated AF for men of 0.003% (95% CI=0.005%-0.01%) giving 1 attributable death and 1 attributable registration (Table 55).

**Table 55** Summary results for occupation as a tin miner

Occupational exposure		Tin miners
'Best study' for RR estimate		Hodgson & Jones (1990)
	Type of study	<i>Cornish tin miners cohort</i>
	Sex	<i>Male</i>
	Exposure level	<i>High</i>
Independent data:		
	Cornish tin miners cohort	2,059
	CAREX adjustment factor	n/a
	Annual employment turnover	n/a
	Numbers exposed in the REP	416
Proportion of the population exposed		0.00002
Relative risks		2.54
Attributable fraction		0.00003
	95% confidence interval	(0.000025 - 0.00004)
Attributable deaths		1
Attributable registrations		1

### 3.25 IRON AND STEEL FOUNDRY WORKERS

#### (a) Risk estimate

A meta-analysis/pooled-analysis of foundry workers could not be identified. However, a UK study of steel foundry workers was identified (Sorahan *et al*, 1994). The study investigated 10,438 men first employed in the period 1946-1965 at nine foundries in England and one in Scotland, and followed then up to 1990. Overall, the SMR was 1.46 (95%CI=1.34-1.58). This was not adjusted for smoking as the data were not available; it was believed by the authors to be unnecessary as it was correlated with employment history variables analysed in the study. In addition the SMRs for other smoking-related cancers were not raised. This result is similar to the results of other European studies (Adzersen *et al*, 2003, Hansen, 1997, Rodriguez *et al*, 2000) and will be used for the risk estimate. All workers are assumed exposed at the same level.

#### (b) Numbers exposed

The number of workers employed in UK foundries, obtained from the LFS for 1979, is given in Table 56. For all other exposures with the exception of environmental tobacco smoke (to which a different set of workers in iron and steel basic industries are likely to be exposed), steel foundry workers have been excluded from the estimates of numbers exposed to avoid double counting.

**Table 56** Numbers of workers employed in foundries in the UK according to the Labour Force Survey.

SIC Code	Description	Men	Women	Total
<b>1979</b>				
159.5	Foremen of workers in foundries	264		264
160.5	Labourers in foundries	15469	567	16036
<b>2003</b>				
9131	Labourers in foundries	3771		3771

#### (c) AF calculation

For lung cancer related to work in iron and steel foundries the estimated total (male and female) attributable fraction is 0.08% (95%CI =0.06%-0.10%), which equates to 25

(95%CI=19-32) deaths and 29 (95%CI=22-37) registrations. The estimated AF for men is 0.13% (95%CI=0.10%-0.16%) resulting in 25(95%CI=18-31) attributable deaths and 28 (95%CI=21-36) attributable registrations; and for women the AF is 0.01% (95%CI=0.01%-0.01%) resulting in 1(95%CI=1-1) attributable death and 1 (95%CI=1-1) attributable registration (Table 57).

**Table 57** Summary results for occupation as an iron and steel worker

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Sorahan <i>et al.</i> , 1994	H	C-E	1.46	15733	1.4	0.09	54358	0.0028	0.0013	0.0010	0.0016	25	18	31	28	21	36
		H	All		15733			54358	0.0028	0.0013	0.0010	0.0016	25	18	31	28	21	36
		All	All		15733			54358	0.0028	0.0013	0.0010	0.0016	25	18	31	28	21	36
Women	Sorahan <i>et al.</i> , 1994	H	C-E	1.46	567	1.5	0.14	3180	0.0002	0.0001	0.0001	0.0001	1	1	1	1	1	1
		H	All		567			3180	0.0002	0.0001	0.0001	0.0001	1	1	1	1	1	1
		All	All		567			3180	0.0002	0.0001	0.0001	0.0001	1	1	1	1	1	1

1. Specific scenario or main industry code -- (Table A1)

2. Relative risks selected from the best study

3. Numbers exposed, allocated to men/women

4. CAREX adjustment factor to mid-REP (Table A1)

5. Staff turnover (TO, Table A1)

6. Number ever exposed during the REP (Statistical Appendix equation 3)

7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)

8. Statistical Appendix equation 1

### 3.26 PAINTERS

#### (a) Risk estimate

Chen and Seaton (1998) carried out a meta-analysis of studies of workers exposed to paints published between 1966 and 1995. A total of 58 were selected. The combined SMR overall among all painters for lung cancer was 1.29 (95%CI=1.19-1.40). The combined SMR for lung cancer among painters from occupational cohort studies (excluding national surveys) was 1.21 (95%CI=1.12-1.31). This has been used for the AF calculation in the present study. The follow-up period for these studies ranged from 1954-62 to 1970-87, indicating that the source relevant exposure periods will at least have pre-dated these periods; the SMRs could represent the effect of exposures up to 50 years, but most probably around 35 years, prior to follow-up.

#### (b) Numbers exposed

The number of painters employed in the UK according to the LFS is given in Table 58. Painters and decorators, and their foremen, are considered to be in the construction sector, and the other codes in manufacturing industry (main industry groups C-E).

**Table 58** Numbers of workers employed in as painters in the UK according to the Labour Force Survey.

SIC Code	Description	Numbers			
		Men	Women	Total	
<b>1979</b>					
132.2	Foremen of Coach Painters (So Described)	0	0	0	
132.3	Foremen of other spray painters	1219	0	1219	
132.4	Foremen of painters & decorators	5066	277	5343	
133.2	Coach painters	5131	0	5131	
133.3	Other spray painters	44660	3027	47687	
133.4	Painters & Decorators	194706	2291	196997	
138.12	Painting assembling & related occupations, nec	10346	17524	27870	<b>284247</b>
<b>2003</b>					
5234	Vehicle spray painters	25272	325	25597	
5323	Painters & Decorators	144429	2562	146991	
24.301&3	Paint, varnish, mastic, sealant manufacture	15452	4255	19707	<b>192295</b>

#### (b) AF calculation

For lung cancer related to work as a painter the estimated total (male and female) attributable fraction is 0.75% (95%CI=0.43%-1.10%), which equates to 246 (95%CI=140-360) deaths and 282 (95%CI=161-413) registrations. The estimated AF for men is 1.20% (95%CI=0.68%-1.75%) resulting in 228 (95%CI=130-333) attributable deaths and 262 (95%CI= 150-384) attributable registrations; and for women the AF is 0.13% (95%CI=0.07%-0.19%) resulting in 18 (95%CI=10-26) attributable deaths and 20 (95%CI=11-30) attributable registrations (Table 59).



**Table 59** Summary results for occupation as a painter

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
Men	Chen and Seaton (1998)	H	C-E	1.21	61356	1.4	0.09	211987	0.0109	0.0023	0.0013	0.0033	43	25	64	50	28	73
		H	F	1.21	199772	1	0.12	906826	0.0467	0.0097	0.0056	0.0143	185	106	272	213	122	314
		H	All		261128			1118813	0.0577	0.0120	0.0068	0.0175	228	130	333	262	150	384
		All	All		261128			1118813	0.0577	0.0120	0.0068	0.0175	228	130	333	262	150	384
Women	Chen and Seaton (1998)	H	C-E	1.21	20551	1.5	0.14	115259	0.0055	0.0012	0.0007	0.0017	16	9	23	18	10	26
		H	F	1.21	2568	0.67	0.15	15371	0.0007	0.0002	0.0001	0.0002	2	1	3	2	1	3
		H	All		23119			130630	0.0062	0.0013	0.0007	0.0019	18	10	26	20	11	30
		All	All		23119			130630	0.0062	0.0013	0.0007	0.0019	18	10	26	20	11	30

1. Specific scenario or main industry code (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

### 3.27 NON-ARSENICAL INSECTICIDES (OCCUPATIONAL EXPOSURE IN SPRAYING AND APPLICATION)

#### (a) Risk estimate

Workers exposed to non-arsenical insecticides in pesticide manufacture and in agriculture will also potentially be exposed to TCDD. The burden estimate for non-arsenical insecticides has therefore been included in the estimate for TCDD. However, grain millers are also potentially exposed to non-arsenical insecticides. A review of the literature on cancer incidence and mortality among pesticide manufacturers and applicators found that the SMR/SIR for lung cancer ranged from 0.4 to 3.2, with an inverse-variance weighted average of 0.99 (95%CI=0.91-1.08) (Burns, 2005). In the present study this estimate has been used as the most appropriate for grain millers.

#### (b) Numbers exposed

The possible numbers of individuals exposed to non-arsenical insecticides are shown in Table 60. The exposed workers are the same as those given under TCDD, apart from grain millers.

**Table 60** Numbers of workers exposed to non-arsenical insecticides in various occupations according to the Labour Force Survey & Census of Employment

SOC/ SIC Code	Job Title	Numbers employed		
		Men	Women	Total
<b>LFS 1979</b>				
40.0	Farmers, horticulturalists, farm managers	208289	17956	226245
76.1	Farm Foremen	6702	236	6938
76.2	Horticultural Foreman	999		999
76.3	Foremen of Gardeners and Groundsmen	8177		8177
76.4	Agricultural Machinery Foremen			0
76.5	Forestry Foremen	1919		1919
76.6	Other Foremen in Farming and Related	759		759
77.0	Farm Workers	135216	29392	164608
78.1	Horticultural Workers	13130	6349	19479
78.2	Gardeners Groundsmen	103171	3535	106706
79.0	Agricultural Machinery Drivers Operators	15168	269	15437
80.0	Forestry Workers	9474		9474
83.0	All Other in Farming and Related	12986	8975	21961
	<i>Total A-B</i>	<i>515990</i>	<i>66712</i>	<i>582702</i>
<b>CoE 1981</b>				
2568	Formulated pesticides	1040	664	1704
4160	Grain milling	8,895	2,064	10,959

#### (c) AF calculation

A relative risk of 1 or less will result in an AF of 0. Therefore an estimate is not required for grain millers, and as the remainder of the exposed group is the same as for dioxins, the attributable fraction has not been estimated to avoid double counting.

### 3.28 ART GLASS

#### (a) Risk estimate

An Italian study of art glass workers found small excess for lung cancer (SMR=1.23, 90%CI=1.00-1.51), which remained when taking account of latency, time since first exposure and adjusting for smoking (Pirastu *et al*, 1998). However, in a more recent study in Sweden

no excess was observed (Wingren, 2004), compared to a previous analysis (Wingren and Englander, 1990), which was attributed to the introduction of preventive actions taken.

Exposures in this industry include arsenic, asbestos, silica and PAHs and therefore as very few are employed in the industry in the UK they will be considered under these other exposures.

**(b) Numbers exposed**

Whilst the numbers of workers in the glass manufacturing industry are quite large, those involved in the production of art glass are small and difficult to obtain. The numbers within the industry as a whole are given in Table 61.

**Table 61** Number of workers employed in the manufacture of glass in 1979 (source LFS)

Description		Number	
		Men	Women
95.1	Foremen glass & ceramics furnace men & kiln setters	966	218
95.2	Foremen glass formers & shapers, finishers, decorators	2409	225
95.3	Foremen glass & ceramics	1460	
96.1	Glass & ceramics furnace men & kiln setters	9701	
96.2	Glass formers & shapers, finishers, decorators	9203	3557
107.5	Glass & ceramics	24141	11936
159.4	Foremen of labourers & unskilled workers in glass & ceramics		
160.4	Labourers & unskilled workers in glass & ceramics		1038

According to industry there are about 6,000 people involved in the manufacture of art glass, glass containers and pressed glassware, with around a further 2,500 working in the flat glass manufacturing sector (Green, personal communication).

**(c) AF calculation**

The AF calculation has not been carried out, to avoid overlap with the other exposures.

**3.29 HAIRDRESSERS AND BARBERS**

**(a) Risk estimate**

An overall relative risk for lung cancer of about 1.3 was found among male and female hairdressers in cohort studies (IARC, 1993a). However, the higher prevalence of smokers among hairdressers and barbers, their own and ETS, in some studies is consistent with the overall excess of lung cancer and was thought by IARC to be the reason for the raised RRs. Therefore, they will be considered under ETS.

**(b) Numbers exposed**

The numbers of hairdressers and barbers according to the LFS for 2003 are given in Table 62.

**Table 62** Number of workers employed as hairdressers and barbers in 2003 (source LFS)

Description	Number
Hairdressers & beauty salon managers/proprietors	29558
Hairdressers & barbers	150974
Hairdressing other beauty treatment	223084

**(c) AF calculation**

The AF calculation was not calculated, as the exposed population are included under environmental tobacco smoke.

**3.30 ISOPROPYL ALCOHOL MANUFACTURE, STRONG ACID PROCESS**

**(a) Risk estimate**

Recent, suitable epidemiological studies could not be identified to obtain a risk estimate. The only study found was published in 1980 (Alderson and Rattan, 1980) and found a significantly fewer lung cancer cases than expected. A US study observed an absence of major risks among strong-acid workers that they explained was due to the initiation of engineering controls and health monitoring that took place after the original medical observations of a previous study (Teta *et al*, 1992).

**(b) Numbers exposed**

The number of workers involved in the manufacture of isopropyl alcohol by the strong acid process could not be identified.

**(c) AF calculation**

The AF calculation is therefore omitted.

**3.31 RUBBER INDUSTRY**

**(a) Risk estimates**

In a review of studies of the rubber industry excess risks of between 1.7 and 3.3 were found in four cohort studies (Kogevinas *et al*, 1998). The review concluded that the moderate excess risk shown in most studies were more consistent than at the time of the IARC evaluation, and that the RRs were >50% in many cohorts, indicating that the excesses found were unlikely to be due solely to confounding by smoking or other lifestyle factors. A more recent study of UK workers observed a decrease in mortality and incidence (Sorahan *et al*, 2000), especially in those first employed after 1982 (Straughan and Sorahan, 2000) (SMR=0.87, 95%CI=0.43-1.55; SIR=0.75, 95%CI=0.28-1.63). A recent meta-analysis of the synthetic rubber-producing industry calculated a pooled estimate of 1.05 (95% CI=0.94-1.18) for mortality, with a high level of heterogeneity (p-value=0.01), and 1.39 (95% CI=0.75-2.59) for incidence (Alder *et al*, 2006). These figures were based on 24 studies. The studies had been carried out in Western Europe, North America, China, Russia and Poland. However, the British cohort study was thought to be most representative of workers throughout the UK rubber industry; the meta-analysis by Alder *et al*. (2006) included studies of the rubber industry from many different countries using several different processes and substances.

**(b) Numbers exposed**

The number of workers in the rubber industry is given in Table 63.

**Table 63** Numbers of workers employed in the rubber industry in the UK according to the Labour Force Survey.

SIC Code	Description	Numbers			
		Men	Women	Total	Grand total
<b>1979</b>					
95.4	Foremen of Rubber Process Workers Moulding Machine Operators Tyre Builders	0	0	0	
95.9	Foremen of Rubber	3710	228	3938	
97.1	Rubber Process Workers Moulding Machine Operators Tyre Builders	13273	1959	15232	
107.1	Rubber	21955	6050	28005	
136.4	Foremen Inspectors Viewers Examiners of Rubber Goods	236	0	236	
138.4	Inspectors Viewers Examiners of Rubber Goods	3109	2860	5969	
					<b>53380</b>
<b>2003</b>					
24.17	Primary synthetic rubber	734	53	787	
25.11	Rubber tyres etc manufacture	9012	1764	10776	
25.12	Rubber tyres retreading etc	2021	343	2364	
25.13	Other rubber products manufacture	18741	4489	23230	
8115	Rubber process operatives	11531	1995	13526	
					<b>50683</b>

**(c) AF calculation**

An AF has not been calculated because the SMR and SIR from the chosen UK study by Sorahan (2000) are less than 1. However, exposure to other carcinogens in the rubber industry is covered under the separate exposure AF estimates for the ‘manufacture of rubber products’ for beryllium, cadmium, chromium, radon, silica, PAHs, lead and cobalt.

**3.32 WELDERS**

**(a) Risk estimate**

Ambroise *et al.* (2006) reviewed a total of 59 studies published between 1954-2004 that included shipyard, mild steel and stainless steel welders. Combined RRs (CRRs) were calculated using fixed and random effects models. Their overall CRR after partial control for publication bias was 1.26 (95%CI=1.20-1.32), for both fixed and random effects and has been used for the AF estimation. There was little difference in the CRR between the types of welders, type of study, or statistic calculated. Smoking did not appear to be a marked confounder in the relationship between lung cancer and welding.

**(b) Numbers exposed**

The number of workers employed as welders is given in Table 64.

**Table 64** Numbers of workers employed as welders in the UK according to the Labour Force Survey.

SIC Code	Description	Numbers			
		Men	Women	Total	Grand total
<b>1979</b>					
124.6	Foremen of welders	4663		4663	
128.0	Welders	153235	14520	167755	172418
<b>2003</b>					
5215	Welding trades	81586	2772	84358	84358

**(c) AF calculation**

**Work as a welder:** For lung cancer related to work as a welder the estimated total (male and female) attributable fraction is 0.46% (95%CI=0.36%-0.57%), which equates to 152 (95%CI=118-188) deaths and 175 (95%CI=135-216) registrations. The estimated AF for men is 0.73% (95%CI=0.56%-0.90%) resulting in 138 (95%CI=107-171) attributable deaths and 159 (95%CI=123-197) attributable registrations; and for women the AF is 0.10% (95%CI=0.08%-0.12%) resulting in 14 (95%CI=11-17) attributable deaths and 16 (95%CI=12-19) attributable registrations (Table 65).

**Table 65** Summary results for occupation as a welder

	Risk Estimate Reference	Exposure	Main Industry Sector <sup>1</sup>	Data		Calculations				Attributable Fraction (Levins <sup>8</sup> ) and Monte Carlo Confidence Interval			Attributable Deaths			Attributable Registrations		
				RR <sup>2</sup>	Ne <sup>3</sup>	Carex adj <sup>4</sup>	TO <sup>5</sup>	NeREP <sup>6</sup>	PrE <sup>7</sup>	AF	LL	UL	AN	LL	UL	AR	LL	UL
<b>Men</b>	<i>Ambroise et al. (2006)</i>	H	C-E	1.26	157898	1.4	0.09	545544	0.0281	0.0073	0.0056	0.0090	138	107	171	159	123	197
		H	All		157898			545544	0.0281	0.0073	0.0056	0.0090	138	107	171	159	123	197
		All	All		157898			545544	0.0281	0.0073	0.0056	0.0090	138	107	171	159	123	197
<b>Women</b>	<i>Ambroise et al. (2006)</i>	H	C-E	1.26	14520	1.5	0.14	81434	0.0039	0.0010	0.0008	0.0012	14	11	17	16	12	19
		H	All		14520			81434	0.0039	0.0010	0.0008	0.0012	14	11	17	16	12	19
		All	All		14520			81434	0.0039	0.0010	0.0008	0.0012	14	11	17	16	12	19

1. Specific scenario or main industry code- (Table A1)
2. Relative risks selected from the best study
3. Numbers exposed, allocated to men/women
4. CAREX adjustment factor to mid-REP (Table A1)
5. Staff turnover (TO, Table A1)
6. Number ever exposed during the REP (Statistical Appendix equation 3)
7. Proportion of the population exposed (Pr(E), Statistical Appendix equation 4)
8. Statistical Appendix equation 1

## 4 OVERALL ATTRIBUTABLE FRACTION

### 4.1 EXPOSURE MAP

The exposure map (Figure 1) gives an indication of how exposures overlap in the working population. It illustrates the potential for double counting of the exposed population to occur when an overall AF is calculated, and facilitates strategies to avoid this. For a given cancer, the map entries consist of either an agent (or group of agents such as PAHs), or an exposure scenario (i.e. an industry or occupation in which such exposure occurs). Agents are in plain type, exposure scenarios in italics, from Table 4. Lines joining boxes then indicate where overlap would occur were all the entries in the map simply considered separately – for example, if painters and asbestos were considered separately overlap would occur in construction (these exposure scenarios are indicated in the smaller print, again based on information in Table 4). For substances and occupations shown not in bold and those in dotted boxes a separate AF has not been estimated, as these exposure scenarios are included with another exposure (Table 20).

For lung cancer, asbestos, silica, DEE, PAHs and occupation as a painter overlap as potential cancer causing exposures in the construction, quarrying and potteries industries and amongst drivers and those employed in personal and household services. These exposures are therefore treated as a set, with the component exposures assumed to act independently of one another. Similarly, arsenic, nickel, chromium, lead and cadmium and exposure to strong inorganic acid mists are all found in the smelting, refining, alloys, plating and battery industries, and are also assumed to act independently of one another, but are not found in the industries listed for the asbestos-silica-DEE-PAHs-painters set, except lead exposure, in plumbers, which overlaps with asbestos exposure in construction, and in printers with mineral oils. Transferring lead to either the asbestos set, or into a product set with mineral oils, does not however affect the overall AF result by more than 0.1% in absolute terms. Exposure to silica and to arsenic also overlaps in the glass industry.

Welders could potentially be exposed to five other carcinogens for which separate estimates have been made, namely nickel, chromium, lead, PAHs and asbestos (see the exposure map) and it is not possible to identify and exclude ‘welders’ specifically from the industry categories used by CAREX for these exposure estimates. There may therefore be some double counting of lung cancer estimates attributed to welding and also to these agents. However, the evidence suggests that other unidentified carcinogenic agents in welding fume may also be contributing to the observed lung cancer risk, or that synergism between the known risk agents may be operating to raise the risk in welders to above that observed in workers exposed to the agents separately. For this reason the separate estimate for welders as an occupation is retained. No attempt has been made to exclude welders from other exposed number estimates.

As regards combining the exposure estimates, welders as an occupation overlaps with two ‘AF product’ sets because of the exposure overlaps noted above. In practice it makes a difference of only 0.1% in absolute terms to the overall AF if the AF for welders is summed directly, or treated as a member of either of the ‘AF product’ sets. Note that the combining of the estimates within ‘AF product sets’ assumes independence of the exposure RRs within the sets.

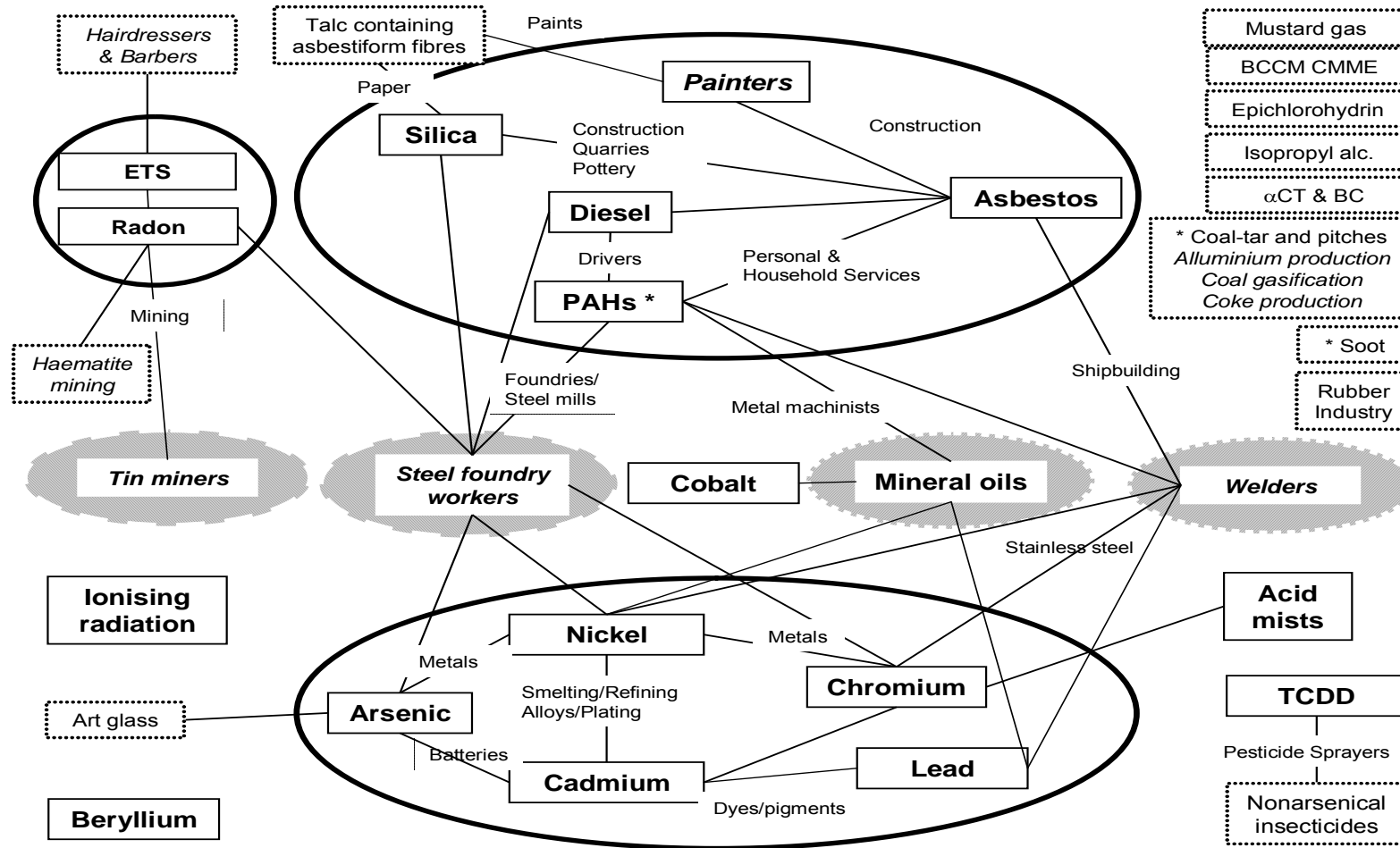
For mineral oils, there is no overlap for printers and it was thought that the workers exposed to printing inks are not specifically included elsewhere (notably under PAHs). However metal machinists (the other main group exposed to mineral oils) do overlap with exposures to some metals (e.g. nickel and lead) and also with PAHs, and it is not possible to specifically exclude metal machinists from the industry categories used by CAREX for these exposure estimates.



Rather than excluding the exposure of metal machinists to mineral oils from the combined AF, a similar approach to that used for welders has been adopted. Again, there is negligible difference in the result if mineral oils are included with the PAHs or metals product sets or summed as an independent third product set with cobalt. Metal machinists also overlap with cobalt exposure.

ETS and indoor radon exposure at work also overlap in high radon areas, so are treated as a fourth product set. No overlap is assumed with other exposures and product sets.

Figure 1



## 4.2 SUMMARY OF RESULTS

The results are summarised in Table 66 and Table 67

**Table 66** Summary of RR used to calculate AF

Agent	Exposure	RR	LL	UL
Arsenic	L	1.74	0.75	3.43
Arsenic	H	2.05	1.43	2.85
Beryllium	L	1	1	1
Beryllium	H	1.12	0.99	1.26
Cadmium	L	1	1	1
Cadmium	H	1.19	1.09	1.29
Chromium VI	L	1	1	1
Chromium VI	H	1.18	1.12	1.25
Cobalt	L	1.3	1	1.66
Cobalt	H	1.93	1.03	3.62
Diesel engine exhaust	L	1.1	0.7	1.8
Diesel engine exhaust	H	1.47	1.29	1.67
ETS (men)	L	1	1	1
ETS (men)	H	1.29	0.93	1.78
ETS (women)	L	1	1	1
ETS (women)	H	1.15	1.04	1.28
Inorganic lead	L	1	1	1
Inorganic lead	H	1.14	1.04	1.73
Ionising radiation (men)	L/H	1.005	1.005	1.005
Ionising radiation (women)	L/H	1.021	1.021	1.021
Mineral oils	B/L	1	1	1
Mineral oils (printers)	H1	1.58	1.28	1.95
Mineral oils	H	1.08	1.04	1.28
Nickel	B	1	1	1
Nickel	L	1.03	0.97	1.1
Nickel	H	1.39	0.92	2.01
PAHs)	<0.01 µg/m <sup>3</sup>	1	1	1
PAHs	0.01-<0.75 µg/m <sup>3</sup>	1.02	1.01	1.03
PAHs	0.75-<2.0 µg/m <sup>3</sup>	1.08	1.04	1.11
PAHs	2.0+ µg/m <sup>3</sup>	1.25	1.13	1.38
Painters	H	1.21	1.12	1.31
Silica	L	1	0.85	1.3
Silica	H	1.32	1.24	1.41
Steel foundry workers	H	1.46	1.34	1.58
Strong inorganic-acid mists, containing sulfuric acid	L	1	1	1
Strong inorganic-acid mists, containing sulfuric acid	H	1.36	0.97	1.94
TCDD	Agriculture	1.03	0.78	1.04
TCDD	Paper and pulp manufacture	1.04	0.96	1.03
TCDD	Other industry sectors	1.12	0.98	1.28
TCDD	Pesticide manufacture	1.22	1.05	1.41
Tin miners	H	2.54	2.18	2.96
Welders	H	1.26	1.2	1.32

**Table 67 Results**

Agent	Numbers of Men Ever Exposed	Numbers of Women Ever Exposed	Proportion of Men Ever Exposed	Proportion of Women Ever Exposed	AF Men	AF Women	Attributable Deaths (Men)	Attributable Deaths (Women)	Attributable Registrations (Men)	Attributable Registrations (Women)
Arsenic	92144	44705	0.0047	0.0021	0.0048	0.0016	91	22	105	24
Asbestos	350302	82336	0.0181	0.0039	0.0892	0.0173	1699	238	1956	267
Beryllium	40180	22142	0.0021	0.0011	0.0002	0.0001	5	2	5	2
Cadmium	130986	58839	0.0068	0.0028	0.0003	0.0002	6	2	7	2
Chromium	444417	243102	0.0229	0.0116	0.0022	0.0011	43	16	49	18
Cobalt	129070	64849	0.0067	0.0031	0.0025	0.0012	47	16	54	18
DEE	1632804	425017	0.0842	0.0202	0.0290	0.0039	552	53	635	60
ETS	758415	1524013	0.0391	0.0726	0.0073	0.0081	138	111	159	125
Inorganic Lead	795404	405530	0.0410	0.0193	0.0016	0.0004	30	5	35	6
Ionising Radiation	252035	39420	0.0130	0.0019	0.0001	0.0000	1	1	1	1
Mineral oils	4770047	574012	0.2459	0.0273	0.0183	0.0045	348	61	401	69
Nickel	305,877	165,889	0.0159	0.0079	0.0003	0.0001	6	2	6	2
PAHs	316278	178332	0.0163	0.0085	0.00003	0.00001	1	0	1	0
Painters	1118813	130630	0.0577	0.0062	0.0120	0.0013	228	18	262	20
Radon	1273684	1327973	0.0657	0.0632	0.0056	0.0056	107	77	123	87
Silica	2525118	256311	0.1302	0.0122	0.0390	0.0033	743	45	856	51
Steel foundry workers	54358	3180	0.0028	0.0002	0.0013	0.0001	25	1	28	1
Strong inorganic-acid mists containing sulfuric acid	136098	96613	0.0070	0.0046	0.0024	0.0016	45	21	52	24
TCDD	2,436,500	687,514	0.1256	0.0327	0.0080	0.0026	152	36	175	40
Tin miners	416	0	0.00002	0.00000	0.0030	0.0000	1	0	1	0
Welders	545544	81434	0.0281	0.0039	0.0073	0.0010	138	14	159	16
<b>Totals*</b>					<b>0.2111</b>	<b>0.0527</b>	<b>4020</b>	<b>725</b>	<b>4627</b>	<b>815</b>

\*Totals are the product sums and are not therefore equal to the sums of the separate estimates of attributable fraction, deaths and registrations for each agent. The difference is especially notable where the constituent AFs are large.

### 4.3 EXPOSURES BY INDUSTRY/JOB

Table 68 shows for industry categories from CAREX and job categories from LFS, attributable registrations in 2004 and attributable deaths in 2005 by agent.

Table 68 Industry/occupation codes by agent

Agent	Industry	Number Ever Exposed over REP (Men)	Number Ever Exposed over REP (Women)	Attributable Registrations (Men) (2004)	Attributable Deaths (Men) (2005)	Attributable Registrations (Women) (2004)	Attributable Deaths (Women) (2005)	Attributable Registrations (Total) (2004)	Attributable Deaths (Total) (2005)
Arsenic	Construction	12,673	113	15	13	0	0	15	13
Arsenic	Electricity, gas and steam	1,118	614	1	1	0	0	1	1
Arsenic	Manufacture of electrical machinery, apparatus, appliances and supplies	5,330	2,928	4	4	2	1	6	5
Arsenic	Manufacture of furniture and fixture, except primary of metal	0	3,075	0	0	2	1	2	1
Arsenic	Manufacture of furniture and fixture, except primary of metal	5,599	0	7	6	0	0	7	6
Arsenic	Manufacture of furniture and fixture, except primary of metal	5,599	3,075	7	6	2	1	8	7
Arsenic	Manufacture of glass and glass products	0	2,592	0	0	1	1	1	1
Arsenic	Manufacture of glass and glass products	4,720	0	6	5	0	0	6	5
Arsenic	Manufacture of glass and glass products	4,720	2,592	6	5	1	1	7	6
Arsenic	Manufacture of industrial chemicals	2,959	1,625	2	2	1	1	3	3
Arsenic	Manufacture of other non-metallic mineral products	816	448	1	1	0	0	1	1
Arsenic	Manufacture of wood and wood and cork products, except furniture	0	12,993	0	0	7	6	7	6
Arsenic	Manufacture of wood and wood and cork products, except furniture	23,656	0	28	24	0	0	28	24
Arsenic	Manufacture of wood and wood and cork products, except furniture	23,656	12,993	28	24	7	6	35	31
Arsenic	Non-ferrous metal basic industries	34,104	0	40	35	0	0	40	35
Arsenic	Non-ferrous metal basic industries	0	18,731	0	0	10	9	10	9
Arsenic	Non-ferrous metal basic industries	34,104	18,731	40	35	10	9	50	44
Arsenic	Sanitary and similar services	501	1,134	0	0	1	1	1	1
<b>Arsenic</b>	<b>Total</b>	<b>92,144</b>	<b>44,705</b>	<b>105</b>	<b>91</b>	<b>24</b>	<b>22</b>	<b>129</b>	<b>113</b>
Asbestos	Construction	209,244	0	1,438	1,249	0	0	1,438	1,249

**Table 68** Industry/occupation codes by agent

Agent	Industry	Number Ever Exposed over REP (Men)	Number Ever Exposed over REP (Women)	Attributable Registrations (Men) (2004)	Attributable Deaths (Men) (2005)	Attributable Registrations (Women) (2004)	Attributable Deaths (Women) (2005)	Attributable Registrations (Total) (2004)	Attributable Deaths (Total) (2005)
Asbestos	Electricity, gas and steam	1,470	0	10	9	0	0	10	9
Asbestos	Land transport	10,002	0	69	60	0	0	69	60
Asbestos	Manufacture of industrial chemicals	4,866	0	33	29	0	0	33	29
Asbestos	Manufacture of other chemical products	5,210	0	36	31	0	0	36	31
Asbestos	Manufacture of paper and paper products	2,791	0	19	17	0	0	19	17
Asbestos	Manufacture of transport equipment	8,668	0	60	52	0	0	60	52
Asbestos	Other mining	66,720	2,368	172	149	8	7	180	156
Asbestos	Personal and household services	31,529	65,510	81	71	213	189	294	260
Asbestos	Petroleum refineries	2,844	0	20	17	0	0	20	17
Asbestos	Sanitary and similar services	1,177	2,446	3	3	8	7	11	10
Asbestos	Wholesale and retail trade and restaurants and hotels	5,781	12,012	15	13	39	35	54	48
<b>Asbestos</b>	<b>Total</b>	<b>350,302</b>	<b>82,336</b>	<b>1,956</b>	<b>1,699</b>	<b>267</b>	<b>238</b>	<b>2,223</b>	<b>1,937</b>
Beryllium	Manufacture of machinery except electrical	30,009	16,481	4	4	1	1	6	5
<b>Beryllium</b>	<b>Total</b>	<b>40,180</b>	<b>22,142</b>	<b>5</b>	<b>5</b>	<b>2</b>	<b>2</b>	<b>7</b>	<b>6</b>
Cadmium	Manufacture of electrical machinery, apparatus, appliances and supplies	4,500	2,471	1	1	0	0	1	1
Cadmium	Manufacture of industrial chemicals	4,128	2,267	1	1	0	0	1	1
Cadmium	Non-ferrous metal basic industries	21,961	12,062	5	4	2	2	6	6
Cadmium	Total	130,986	58,839	7	6	2	2	9	8
Chromium	Manufacture of fabricated metal products, except machinery and equipment	77,339	42,476	16	14	6	5	21	19
Chromium	Manufacture of industrial chemicals	11,102	6,097	2	2	1	1	3	3
Chromium	Manufacture of machinery except electrical	83,787	46,018	17	15	6	5	23	20
Chromium	Manufacture of other chemical products	5,977	3,283	1	1	0	0	2	1
Chromium	Manufacture of transport equipment	53,238	29,240	11	9	4	3	15	13
Chromium	Non-ferrous metal basic industries	8,705	4,781	2	2	1	1	2	2
Chromium	Other manufacturing industries	2,279	1,252	0	0	0	0	1	1
<b>Chromium</b>	<b>Total</b>	<b>444,417</b>	<b>243,102</b>	<b>49,2015</b>	<b>43</b>	<b>18</b>	<b>16</b>	<b>67</b>	<b>58</b>

**Table 68** Industry/occupation codes by agent

Agent	Industry	Number Ever Exposed over REP (Men)	Number Ever Exposed over REP (Women)	Attributable Registrations (Men) (2004)	Attributable Deaths (Men) (2005)	Attributable Registrations (Women) (2004)	Attributable Deaths (Women) (2005)	Attributable Registrations (Total) (2004)	Attributable Deaths (Total) (2005)
Cobalt	Air transport	3,089	2,118	1	1	0	0	2	1
Cobalt	Construction	12,129	108	4	4	0	0	4	4
Cobalt	Food manufacturing	8,176	4,490	3	2	1	1	4	3
Cobalt	Manufacture of electrical machinery, apparatus, appliances and supplies	1,353	743	0	0	0	0	1	1
Cobalt	Manufacture of fabricated metal products, except machinery and equipment	23,226	12,756	8	7	3	3	11	9
Cobalt	Manufacture of furniture and fixture, except primary of metal	16,238	8,918	5	5	2	2	7	7
Cobalt	Manufacture of glass and glass products	1,875	1,030	1	1	0	0	1	1
Cobalt	Manufacture of industrial chemicals	4,242	2,330	4	4	2	1	6	5
Cobalt	Manufacture of instruments, photographic and optical goods	3,757	2,063	1	1	0	0	2	2
Cobalt	Manufacture of machinery except electrical	11,426	6,275	4	3	1	1	5	5
Cobalt	Manufacture of other chemical products	6,874	3,776	7	6	3	2	10	9
Cobalt	Manufacture of paper and paper products	1,364	749	0	0	0	0	1	1
Cobalt	Manufacture of plastic products not elsewhere classified	1,522	836	1	0	0	0	1	1
Cobalt	Manufacture of pottery, china and earthenware	1,743	957	1	1	0	0	1	1
Cobalt	Manufacture of transport equipment	8,551	4,696	3	3	1	1	4	3
Cobalt	Manufacture of wearing apparel, except footwear	2,147	1,179	1	1	0	0	1	1
Cobalt	Manufacture of wood and wood and cork products, except furniture	4,919	2,701	2	1	1	1	2	2
Cobalt	Non-ferrous metal basic industries	4,033	2,215	4	4	2	1	6	5
Cobalt	Printing, publishing and allied industries	9,235	5,072	3	3	1	1	4	4
<b>Cobalt</b>	<b>Total</b>	<b>129,070</b>	<b>64,849</b>	<b>54</b>	<b>47</b>	<b>18</b>	<b>16</b>	<b>73</b>	<b>63</b>
DEE	Air transport	16,551	11,349	2	2	1	1	3	2
DEE	Beverage industries	17,131	9,409	2	2	1	1	3	2
DEE	Communication	15,341	10,520	2	1	1	1	2	2

**Table 68** Industry/occupation codes by agent

Agent	Industry	Number Ever Exposed over REP (Men)	Number Ever Exposed over REP (Women)	Attributable Registrations (Men) (2004)	Attributable Deaths (Men) (2005)	Attributable Registrations (Women) (2004)	Attributable Deaths (Women) (2005)	Attributable Registrations (Total) (2004)	Attributable Deaths (Total) (2005)
DEE	Construction	479,312	4,277	247	215	1	1	249	216
DEE	Crude petroleum and natural gas production	27,681	15,203	3	3	1	1	4	4
DEE	Electricity, gas and steam	13,951	7,662	2	1	1	0	2	2
DEE	Food manufacturing	14,190	7,793	2	1	1	1	2	2
DEE	Land transport	524,570	91,095	271	235	31	28	302	263
DEE	Manufacture of electrical machinery, apparatus, appliances and supplies	4,500	2,471	0	0	0	0	1	1
DEE	Manufacture of fabricated metal products, except machinery and equipment	14,411	7,915	2	1	1	1	2	2
DEE	Manufacture of industrial chemicals	5,834	3,204	1	1	0	0	1	1
DEE	Manufacture of machinery except electrical	11,602	6,372	1	1	0	0	2	2
DEE	Manufacture of other chemical products	5,099	2,800	1	0	0	0	1	1
DEE	Manufacture of other non-metallic mineral products	42,691	23,447	5	4	2	2	6	6
DEE	Manufacture of paper and paper products	4,206	2,310	0	0	0	0	1	1
DEE	Manufacture of textiles	3,709	2,037	0	0	0	0	1	0
DEE	Manufacture of transport equipment	9,462	5,197	1	1	0	0	1	1
DEE	Manufacture of wearing apparel, except footwear	4,117	2,261	0	0	0	0	1	1
DEE	Manufacture of wood and wood and cork products, except furniture	14,763	8,108	2	1	1	1	2	2
DEE	Metal ore mining	3,058	109	2	1	0	0	2	1
DEE	Non-ferrous metal basic industries	9,753	5,357	1	1	0	0	1	1
DEE	Other mining	66,720	2,368	34	30	1	1	35	31
DEE	Personal and household services	168,533	115,566	18	16	8	8	27	24
DEE	Public administration and defence	6,120	4,197	1	1	0	0	1	1
DEE	Sanitary and similar services	10,336	7,088	1	1	1	0	2	1
DEE	Services allied to transport	48,899	8,492	25	22	3	3	28	25
DEE	Water transport	31,756	21,775	3	3	2	1	5	4
DEE	Water works and supply	15,054	8,268	2	1	1	1	2	2



**Table 68** Industry/occupation codes by agent

Agent	Industry	Number Ever Exposed over REP (Men)	Number Ever Exposed over REP (Women)	Attributable Registrations (Men) (2004)	Attributable Deaths (Men) (2005)	Attributable Registrations (Women) (2004)	Attributable Deaths (Women) (2005)	Attributable Registrations (Total) (2004)	Attributable Deaths (Total) (2005)
DEE	Wholesale and retail trade and restaurants and hotels	32,963	22,603	4	3	2	1	5	5
<b>DEE</b>	<b>Total</b>	<b>1,632,804</b>	<b>425,017</b>	<b>635</b>	<b>552</b>	<b>60</b>	<b>53</b>	<b>695</b>	<b>605</b>
ETS	Air transport	17,381	50,929	6	5	6	5	11	10
ETS	Business, professional and other organisation	1,200	3,517	0	0	0	0	1	1
ETS	Communication	10,612	31,095	3	3	3	3	7	6
ETS	Construction	105,536	18,074	34	30	2	2	36	32
ETS	Education services	6,293	18,439	2	2	2	2	4	4
ETS	Financing, insurance, real estate and business services	51,623	151,262	17	15	17	15	33	29
ETS	Land transport	4,659	13,652	2	1	1	1	3	3
ETS	Personal and household services	33,754	98,902	11	10	11	10	22	19
ETS	Public administration and defence	31,003	90,843	10	9	10	9	20	18
ETS	Recreational and cultural services	13,871	40,644	5	4	4	4	9	8
ETS	Research and scientific institutes	1,576	4,617	1	0	1	0	1	1
ETS	Sanitary and similar services	4,744	13,899	2	1	2	1	3	3
ETS	Services allied to transport	9,379	27,481	3	3	3	3	6	5
ETS	Water transport	5,895	17,273	2	2	2	2	4	3
ETS	Welfare institutions	7,979	23,379	3	2	3	2	5	5
ETS	Wholesale and retail trade and restaurants and hotels	183,356	537,251	60	52	59	52	118	104
<b>ETS</b>	<b>Total</b>	<b>758,415</b>	<b>1,524,013</b>	<b>159</b>	<b>138</b>	<b>125</b>	<b>111</b>	<b>284</b>	<b>249</b>
Inorganic Lead	Construction	122,855	1,096	19	17	0	0	20	17
Inorganic Lead	Manufacture of electrical machinery, apparatus, appliances and supplies	28,601	15,708	5	4	2	1	6	5
Inorganic Lead	Manufacture of industrial chemicals	6,455	3,545	1	1	0	0	1	1
Inorganic Lead	Manufacture of other chemical products	9,977	5,480	2	1	1	1	2	2
Inorganic Lead	Manufacture of plastic products not elsewhere classified	27,887	15,316	4	4	2	1	6	5
Inorganic Lead	Manufacture of rubber products	3,077	1,690	0	0	0	0	1	1

**Table 68** Industry/occupation codes by agent

Agent	Industry	Number Ever Exposed over REP (Men)	Number Ever Exposed over REP (Women)	Attributable Registrations (Men) (2004)	Attributable Deaths (Men) (2005)	Attributable Registrations (Women) (2004)	Attributable Deaths (Women) (2005)	Attributable Registrations (Total) (2004)	Attributable Deaths (Total) (2005)
Inorganic Lead	Non-ferrous metal basic industries	22,792	12,518	4	3	1	1	5	4
<b>Inorganic Lead</b>	<b>Total</b>	<b>795,404</b>	<b>405,530</b>	<b>35</b>	<b>30</b>	<b>6</b>	<b>5</b>	<b>41</b>	<b>36</b>
<b>Ionising Radiation</b>	<b>Total</b>	<b>252,035</b>	<b>39,420</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>
Mineral oils	Printing machine minders and assistants	147,592	73,998	95	83	31	28	126	110
Mineral oils	Printers (so described)	172,026	29,792	111	96	13	11	123	107
Mineral oils	Press and machine tool setters	221,665	4,150	20	17	0	0	20	17
Mineral oils	Other centre lathe turners	171,971	0	15	13	0	0	15	13
Mineral oils	Machine tool setter operators	37,377	1,301	3	3	0	0	3	3
Mineral oils	Machine tool operators	1,157,773	282,800	103	89	17	15	119	104
Mineral oils	Press stamping and automatic machine operators	117,478	102,528	10	9	6	5	16	14
Mineral oils	Toolmakers tool fitters markers-out	320,925	2,860	28	25	0	0	29	25
Mineral oils	Foremen of printing machine minders and assistants	18,374	2,647	12	10	1	1	13	11
Mineral oils	Foremen of printers (so described)	5,473	1,324	4	3	1	1	4	4
<b>Mineral oils</b>	<b>Total</b>	<b>4,770,047</b>	<b>574,012</b>	<b>401</b>	<b>348</b>	<b>69</b>	<b>61</b>	<b>470</b>	<b>410</b>
Mineral oils	Metal Workers	3,811,384	432,528	151	132	23	20	174	152
Mineral oils	Printers (Printing, publishing and allied industries)	343,465	107,760	221	192	46	41	267	233
Mineral oils	Watch makers (Personal and household services)	22,551	1,262	0	0	0	0	0	0
Mineral oils	Precision instrument and tool makers (Manufacture of instruments, photographic and optical goods)	436,181	12,210	28	25	0	0	29	25
Nickel	Manufacture of fabricated metal products, except machinery and equipment	101,815	55,919	3	3	1	1	5	4
Nickel	Manufacture of transport equipment	47,426	26,048	2	1	1	1	2	2
Nickel	Metal ore mining	1,835	65	0	0	0	0	0	0
Nickel	Non-ferrous metal basic industries	34,512	18,955	1	1	0	0	2	1
Nickel	Clydach	164		0	01	0	0	1	1
<b>Nickel</b>	<b>Total</b>	<b>305,877</b>	<b>165,888</b>	<b>6</b>	<b>6</b>	<b>2</b>	<b>2</b>	<b>9</b>	<b>8</b>

**Table 68** Industry/occupation codes by agent

Agent	Industry	Number Ever Exposed over REP (Men)	Number Ever Exposed over REP (Women)	Attributable Registrations (Men) (2004)	Attributable Deaths (Men) (2005)	Attributable Registrations (Women) (2004)	Attributable Deaths (Women) (2005)	Attributable Registrations (Total) (2004)	Attributable Deaths (Total) (2005)
<b>PAHs</b>	<b>Total</b>	<b>316,278</b>	<b>178,332</b>	<b>1</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>1</b>
Painters	Foremen of other spray painters	4,212	0	1	1	0	0	1	1
Painters	Foremen of painters and decorators	22,996	1,658	5	5	0	0	6	5
Painters	Coach painters	17,728	0	4	4	0	0	4	4
Painters	Other spray painters	154,302	16,977	36	31	3	2	39	34
Painters	Painters and decorators	883,830	13,713	207	180	2	2	209	182
Painters	Painting assembling and related occupations, nec	35,746	98,282	8	7	15	13	24	21
<b>Painters</b>	<b>Total</b>	<b>1,118,813</b>	<b>130,630</b>	<b>262</b>	<b>228</b>	<b>20</b>	<b>18</b>	<b>282</b>	<b>246</b>
Painters	Painters and decorators (construction)	906,826	15,371	213	185	2	2	215	187
Painters	Painters (not construction)	211,987	115,259	50	43	18	16	67	59
Radon	Agriculture and hunting	4,351	1,302	0	0	0	0	1	0
Radon	Air transport	4,130	6,175	0	0	0	0	1	1
Radon	Beverage industries	9,716	5,336	1	1	0	0	1	1
Radon	Business, professional and other organisation	5,870	8,776	1	0	1	1	1	1
Radon	Communication	13,837	20,686	1	1	1	1	3	2
Radon	Construction	88,043	7,693	8	7	1	0	9	8
Radon	Education services	71,004	106,147	7	6	7	6	14	12
Radon	Electricity, gas and steam	11,977	6,578	1	1	0	0	2	1
Radon	Financing, insurance, real estate and business services	135,466	202,515	13	11	13	12	26	23
Radon	Food manufacturing	43,846	24,081	4	4	2	1	6	5
Radon	Iron and steel basic industries	4,746	2,607	0	0	0	0	1	1
Radon	Land transport	19,832	29,648	2	2	2	2	4	3
Radon	Manufacture of electrical machinery, apparatus, appliances and supplies	51,209	28,125	5	4	2	2	7	6
Radon	Manufacture of fabricated metal products, except machinery and equipment	29,641	16,279	3	2	1	1	4	3
Radon	Manufacture of footwear	4,275	2,348	0	0	0	0	1	0
Radon	Manufacture of furniture and fixture, except primary of metal	15,285	8,395	1	1	1	0	2	2
Radon	Manufacture of industrial chemicals	12,903	7,087	1	1	0	0	2	1

**Table 68** Industry/occupation codes by agent

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Radon	Manufacture of instruments, photographic and optical goods	9,481	5,207	1	1	0	0	1	1
Radon	Manufacture of machinery except electrical	67,976	37,334	7	6	2	2	9	8
Radon	Manufacture of other chemical products	18,146	9,966	2	2	1	1	2	2
Radon	Manufacture of other non-metallic mineral products	6,169	3,388	1	1	0	0	1	1
Radon	Manufacture of paper and paper products	11,687	6,419	1	1	0	0	2	1
Radon	Manufacture of plastic products not elsewhere classified	13,741	7,547	1	1	0	0	2	2
Radon	Manufacture of pottery, china and earthenware	4,698	2,580	0	0	0	0	1	1
Radon	Manufacture of rubber products	5,849	3,212	1	0	0	0	1	1
Radon	Manufacture of textiles	20,109	11,044	2	2	1	1	3	2
Radon	Manufacture of transport equipment	39,916	21,923	4	3	1	1	5	5
Radon	Manufacture of wearing apparel, except footwear	20,289	11,143	2	2	1	1	3	2
Radon	Manufacture of wood and wood and cork products, except furniture	11,576	6,358	1	1	0	0	2	1
Radon	Medical, dental, other health and veterinary services	72,562	108,477	7	6	7	6	14	12
Radon	Non-ferrous metal basic industries	7,801	4,284	1	1	0	0	1	1
Radon	Other manufacturing industries	6,547	3,596	1	1	0	0	1	1
Radon	Personal and household services	32,346	48,356	3	3	3	3	6	6
Radon	Printing, publishing and allied industries	33,247	18,260	3	3	1	1	4	4
Radon	Public administration and defence	63,533	94,979	6	5	6	6	12	11
Radon	Recreational and cultural services	22,197	33,183	2	2	2	2	4	4
Radon	Research and scientific institutes	3,973	5,939	0	0	0	0	1	1
Radon	Sanitary and similar services	10,385	15,525	1	1	1	1	2	2
Radon	Services allied to transport	6,007	8,980	1	1	1	1	1	1
Radon	Water transport	2,833	4,235	0	0	0	0	1	0
Radon	Welfare institutions	29,788	44,532	3	2	3	3	6	5
Radon	Wholesale and retail trade and restaurants and hotels	215,401	322,014	21	18	21	19	42	37

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<b>Radon</b>	<b>Total</b>	<b>1,273,684</b>	<b>1,327,973</b>	<b>123</b>	<b>107</b>	<b>87</b>	<b>77</b>	<b>209</b>	<b>184</b>
Silica	Construction	2,021,946	18,043	703	610	4	4	707	614
Silica	Electricity, gas and steam	12,433	6,828	4	4	2	1	6	5
Silica	Manufacture of fabricated metal products, except machinery and equipment	29,417	16,156	10	9	4	3	14	12
Silica	Manufacture of glass and glass products	25,483	13,996	9	8	3	3	12	11
Silica	Manufacture of industrial chemicals	2,272	1,248	1	1	0	0	1	1
Silica	Manufacture of machinery except electrical	59,749	32,815	21	18	8	7	28	25
Silica	Manufacture of miscellaneous products of petroleum and coal	1,066	586	0	0	0	0	1	0
Silica	Manufacture of other chemical products	20,814	11,432	7	6	3	2	10	9
Silica	Manufacture of other non-metallic mineral products	89,720	49,277	31	27	12	10	43	37
Silica	Manufacture of pottery, china and earthenware	80,026	43,952	28	24	10	9	38	33
Silica	Manufacture of transport equipment	23,601	12,962	8	7	3	3	11	10
Silica	Metal ore mining	5,504	195	2	2	0	0	2	2
Silica	Non-ferrous metal basic industries	8,845	4,858	3	3	1	1	4	4
Silica	Other manufacturing industries	4,838	2,657	2	1	1	1	2	2
Silica	Other mining	76,983	2,732	27	23	1	1	27	24
<b>Silica</b>	<b>Total</b>	<b>2,525,118</b>	<b>256,311</b>	<b>856</b>	<b>743</b>	<b>51</b>	<b>45</b>	<b>907</b>	<b>789</b>
Steel foundry workers	Labourers and other unskilled workers in foundries in engineering	53,446	3,180	28	24	1	1	29	25
<b>Steel foundry workers</b>	<b>Total</b>	<b>54,358</b>	<b>3,180</b>	<b>28</b>	<b>25</b>	<b>1</b>	<b>1</b>	<b>29</b>	<b>25</b>
Strong inorganic-acid mists containing sulfuric acid	Manufacture of electrical machinery, apparatus, appliances and supplies	16,368	11,627	7	6	3	3	10	9
SIAM*	Manufacture of fabricated metal products, except machinery and equipment	18,896	13,423	8	7	4	3	11	10
SIAM*	Manufacture of industrial chemicals	17,810	12,652	7	6	3	3	11	9

**Table 68** Industry/occupation codes by agent

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SIAM*	Manufacture of leather and products of leather or of its substitutes	2,610	1,854	1	1	0	0	2	1
SIAM*	Manufacture of machinery except electrical	13,703	9,734	6	5	3	2	8	7
SIAM*	Manufacture of other chemical products	21,293	15,126	9	8	4	4	13	11
SIAM*	Manufacture of paper and paper products	10,282	7,304	4	4	2	2	6	5
SIAM*	Manufacture of transport equipment	12,673	9,002	5	4	2	2	8	7
SIAM*	Non-ferrous metal basic industries	14,743	10,474	6	5	3	2	9	8
<b>SIAM*</b>	<b>Total</b>	<b>136,098</b>	<b>96,613</b>	<b>52</b>	<b>45</b>	<b>24</b>	<b>21</b>	<b>76</b>	<b>67</b>
TCDD	Agricultural machinery drivers and operators	41,442	1,103	1	1	0	0	1	1
TCDD	All other in farming and related	35,480	36,799	1	1	1	1	2	2
TCDD	Aluminium and aluminium alloys	93,213	26,343	13	11	2	2	15	13
TCDD	Cement, lime, and plaster manufacture	48,391	9,433	7	6	1	1	7	6
TCDD	Ceramic goods	92,633	115,164	12	11	10	9	23	20
TCDD	Copper, brass and other copper alloys	79,017	26,601	11	9	2	2	13	11
TCDD	Farm foremen	18,311	968	1	1	0	0	1	1
TCDD	Farm workers	369,436	120,513	12	11	3	2	15	13
TCDD	Farmers, horticulturalists, farm managers	569,086	73,623	19	17	2	1	21	18
TCDD	Flat glass manufacture	45,734	17,526	6	5	2	1	8	7
TCDD	Foremen of gardeners and groundsmen	22,341	0	1	1	0	0	1	1
TCDD	Forestry workers	25,885	0	1	1	0	0	1	1
TCDD	Formulated pesticides	3,593	3,724	1	1	1	1	1	1
TCDD	Gardeners and groundsmen	281,883	14,494	9	8	0	0	10	9
TCDD	Glass containers	41,046	11,172	6	5	1	1	7	6
TCDD	Horticultural workers	35,874	26,032	1	1	1	1	2	2
TCDD	Organic chemical manufacture	36,817	12,838	5	4	1	1	6	5
TCDD	Other drawing cold rolling forming of steel	17,925	3,584	2	2	0	0	3	2
TCDD	Other glass products	69,885	42,658	9	8	4	3	13	12
TCDD	Other non-ferrous metals and their alloys	57,001	18,323	8	7	2	1	9	8
TCDD	Pulp manufacture	126,676	43,544	6	5	1	1	7	6
TCDD	Refractory goods	37,857	8,962	5	4	1	1	6	5

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TCDD	Scrap dealers general dealers rag and bone merchants	38,236	2,771	5	4	0	0	5	5
TCDD	Manufacture of steel tubes	98,026	24,980	13	11	2	2	15	13
TCDD	Manufacture of steel wire and wire products	67,833	27,756	9	8	2	2	12	10
TCDD	Wood sawmill planning impregnation	72,832	18,603	10	9	2	1	11	10
<b>TCDD</b>	<b>Total</b>	<b>2,436,500</b>	<b>687,514</b>	<b>175</b>	<b>152</b>	<b>40</b>	<b>36</b>	<b>215</b>	<b>187</b>
TCDD	Farming	1,035,829	233,006	35	30	5	5	40	35
TCDD	Forestry	31,128	0	1	1	0	0	1	1
TCDD	Horticulture	342,828	40,526	12	10	1	1	12	11
Tin miners	Cornish tin miners cohort	426	0	1	1	0	0	1	1
Welders	Foremen of welders	16,111	0	5	4	0	0	5	4
Welders	Welders	529,433	81,434	154	134	16	14	170	148
<b>Welders</b>	<b>Total</b>	<b>545,544</b>	<b>81,434</b>	<b>159</b>	<b>138</b>	<b>16</b>	<b>14</b>	<b>175</b>	<b>152</b>

\*Strong inorganic acid mists containing sulphuric acid

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## 6 ANNEX 1 – ESTIMATED NUMBERS OF DEATHS FROM RADON EXPOSURE AT WORK

The estimate follows an NRPB report that estimated 2,000 domestic deaths from lung cancer are caused by exposure to radon. It should be noted that most of this exposure arises in buildings below the Action Level and that only perhaps 10% or so is likely to be reducible through work to reduce radon in existing buildings (referred to as avoidable).

The calculation assumes:

- UK population of 58M and estimated 28M employees
- Exposure times inside buildings of 7,000 hours domestic and 2,000 work
- Average radon concentration at work is similar to homes.

The calculation for estimated total occupational deaths from radon is:

$$2000 \times 28/58 \times 2000/7000 = 276, \text{ of which about 28 are avoidable}$$

### **Duration of exposure for employees in buildings**

Annual working time is traditionally 2,000 hours, which is 40 hours per week with only two weeks absence per year. However, few people work such hours now and allowing for longer leave allowance and public holidays a typical working year is probably now significantly shorter. Furthermore, not all employees will spend the full working day at a single work location. Taking account of periods of the working day spent at locations other than the principal work station, the range of exposed times is taken to be from 1,600 to 2,000 hours.

### **Outdoor occupations**

Many occupations involve substantial periods outside the workplace building, including for example, farmers, delivery drivers, teachers, salesmen, building or construction workers, site inspectors, etc. The proportion of the working population that is indoors can be estimated crudely by allocating the different work classifications used by Local Authority statistics into four categories, wholly indoors, majority indoors, majority outdoors and wholly outdoors. The number employed in each sector can then be adjusted and summed to provide a guide to the total indoor working population. As a preliminary estimate this fraction is taken to be 70-90%.

### **Average concentration during work**

Compared to houses, a workplace overnight will generally have less ventilation (higher radon) and probably be cooler (lower radon), and during the day will tend to have higher ventilation (lower radon). Overall, therefore, long-term average levels in a workplace will probably be lower than a comparable building occupied domestically. This factor will depend on building use but in the absence of better data a nominal 10% reduction on cumulative exposure is assumed. The radon concentration in a normal heated building during the day is substantially lower than the average indicated by passive monitors. This effect is not well quantified for workplaces and will vary with the type and use of building. We currently assume that the average eight-hour level in a workplace during the day to be 75% of the value measured over three months. The magnitude of these factors is not well known and likely to be very variable. As an overall guide the factor, including diurnal variation, is assumed to lie in the range 60-90%.

### **Conclusion from domestic comparison**

(a) lower end of range

$$2000 \times 28/58 \times 1600/7000 \times 0.7 \times 0.6 = 93, \text{ of which about 9 are avoidable}$$

(b) upper end of range

$2000 \times 28/58 \times 2000/7000 \times 0.9 \times 0.9 = 223$ , of which about 22 are avoidable

Indicative overall range 93 – 276, of which about 10% are avoidable

## 7. STATISTICAL APPENDIX

### Formulae used in the estimation of AF

Levin's equation

$$AF = Pr(E) * (RR-1) / \{1 + Pr(E) * (RR-1)\} \quad (1)$$

where RR = relative risk, Pr(E) = proportion of the population exposed

A common denominator is used across exposure levels and industries for each exposure

Miettinen's equation

$$AF = Pr(E|D) * (RR-1) / RR \quad (2)$$

where Pr(E|D) = proportion of cases exposed (E = exposed, D = case)

Turnover equation to estimate numbers ever employed during the REP

$$N_{e(REP)} = \sum_{i=a}^{i=b} l_{(adj15)i} * n_0 / (R-15) \} + \sum_{k=0}^{k=(age(u)-age(l))} \sum_{j=c+k}^{j=d+k} \{l_{(adj15)j} * n_0 * TO / (age(u)-age(l)+1)\} \quad (3)$$

where  $N_{e(REP)}$  = numbers ever employed in the REP

$n_0$  = numbers employed in the exposed job/industry at a mid-point in the REP

TO = staff turnover per year

R = retirement age (65 for men, 60 for women)

$l_{(adj15)i}$  = the proportion of survivors to age i of those alive at age 15 (from GB life tables)

a to b = age range achieved by the original cohort members by the target year (2004)  
(e.g. 65 to 100 for the solid tumour REP)

c to d = age range achieved by the turnover recruited cohort members by the target year  
(25 to 64 for the solid tumour REP)

age(u) and age(l) = upper and lower recruitment age limits (24 and 15)

The derivation and assumptions underlying this formula are described in the methodology technical report, available on the HSE website. The equation can be represented as a single factor acting as a multiplier for  $n_0$ , calculated by setting  $n_0$  to 1 in the above equation, so that the factor varies only with TO see Table A1 below.

Equation to estimate the proportion of the population exposed

$$Pr(E) = N_{e(REP)} / N_{p(REP)} \quad (4)$$

where  $N_{p(REP)}$  = numbers ever of working age during the REP from population estimates for the relevant age cohorts in the target year

Equation for combining AFs where exposed populations overlap but are independent and risk estimates are assumed to be multiplicative:

$$AF_{overall} = 1 - \prod_k (1 - AF_k) \text{ for the } k \text{ exposures in the set} \quad (5)$$

**Table A1** Employment level adjustment and turnover factors used in the calculation of AF

		<b>Main Industry Sector</b>	<b>Adjustment factor for change in employment levels*</b>	<b>Turnover per year</b>
Men	A-B	Agriculture, hunting and forestry; fishing	1	7%
	C-E	Mining and quarrying, electricity, gas and water; manufacturing industry	1.4	9%
	F	Construction	1	12%
	G-Q	Service industries	0.9	11%
		Total	1	10%
Women	A-B	Agriculture, hunting and forestry; fishing	0.75	10%
	C-E	Mining and quarrying, electricity, gas and water; manufacturing industry	1.5	14%
	F	Construction	0.67	15%
	G-Q	Service industries	0.8	15%
		Total	0.9	14%

\* Applied to CAREX data for the solid tumour REP only. Exposed numbers are obtained for a mid-point year in the REP where national employment data sources have been used (the LFS or CoE).

# The burden of occupational cancer in Great Britain

## Lung cancer

The aim of this project was to produce an updated estimate of the current burden of cancer for Great Britain resulting from occupational exposure to carcinogenic agents or exposure circumstances. The primary measure of the burden of cancer was the attributable fraction (AF) being the proportion of cases that would not have occurred in the absence of exposure; and the AF was used to estimate the number of attributable deaths and registrations. The study involved obtaining data on the risk of the cancer due to the exposure of interest, taking into account confounding factors and overlapping exposures, as well as the proportion of the target population exposed over the relevant exposure period. Only carcinogenic agents, or exposure circumstances, classified by the International Agency for Research on Cancer (IARC) as definite (Group 1) or probable (Group 2A) human carcinogens were considered. Here, we present estimates for cancer of the lung that have been derived using incidence data for calendar year 2004, and mortality data for calendar year 2005.

The estimated total (male and female) AF, deaths and registrations for lung cancer related to overall occupational exposure is 14.47% (95% Confidence Interval (CI)= 12.96-17.20), which equates to 4745 (95%CI= 4251-5643) attributable deaths and 5442 (95%CI=4877-6469) attributable registrations.

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