Full Paper

Occupational cancer in Britain
Industry sector resultsSally J Hutchings¹ and Lesley Rushton^{*,1} with the British Occupational Cancer Burden Study Group¹Department of Epidemiology and Biostatistics, School of Public Health and MRC-HPA Centre for Environment and Health, Imperial College London, St Mary's Campus, Norfolk Place, London W2 3PG, UKBritish Journal of Cancer (2012) 107, S92–S103; doi:10.1038/bjc.2012.123 www.bjcancer.com
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A key feature of this project is the estimation of broad industry sectors for each carcinogen, occupational circumstance and cancer site. This information is critical to prioritise interventions that aim to reduce workplace-related cancer. This paper presents results for the current burden of occupational cancer by industry sector on the basis of attributable cancer registrations for 2004, for all industries for which there are at least 10 attributable registrations.

METHODOLOGY

Risk exposure periods (REP)

The occupational exposures that were relevant to cancers registered in 2004 (or cancer deaths in 2005) are those that occurred during an REP defined as the period during which exposure occurred that was relevant to the development of the cancer in the target year 2005, which for this study we have assumed is between 10 and 50 years for all solid tumour cancers, giving an REP for 2005 of 1956–1995, and between 0 and 20 years for the haematopoietic malignancies, which have shorter latencies, giving an REP of 1986–2005.

Classification of industries and occupations

Three main sources of data have been used to estimate the proportion of workers exposed to carcinogenic agents identified by the International Agency for Research on Cancer (IARC) as Group 1 and 2A carcinogens. These sources were the CARcinogenic EXposure database (CAREX), available for 1991–1993, the UK Labour Force Survey (LFS; LFS, 2009) for 1979 and 1991 for long and short latency cancer REPs, respectively; and the UK Census of Employment (CoE, 1981 for the long latency REP). Different industry and occupational classifications have been used in these surveys and over time. These have been consolidated by the research team into a single set of 60 industries (see HSE 2012b),

based mainly on the industry descriptions from the classification used for CAREX (United Nations International Standard Industrial Codes Revision 2 (1968), matched to Standard Industrial Codes (SIC) 68 codes) (Kauppinen *et al*, 1998; Pannett *et al*, 1998). They also have been grouped into four main industry sectors: 'farming, forestry and fishing' (LFS main industry sectors A and B), 'mining, manufacturing and utilities' (LFS main industry sectors C–E), 'construction' (LFS main industry sector F) and the 'service sector' (LFS main industry sectors G–Q).

Estimating numbers exposed

The number of people employed in the industry and exposed for at least 1 year in the appropriate cancer REP have been estimated by applying turnover rates for the groups described above (Hutchings and Rushton, 2012). To take account of the change in the number of people employed (in primary and manufacturing industry and service sectors in Britain) over the long latency REP employment level, adjustment factors for these groups were also applied to 'point estimate' CAREX data (Hutchings and Rushton, 2012). Estimates of numbers of workers ever exposed by agent or exposure circumstance are available for all industries in the overview report on the Health and Safety Executive (HSE) website (HSE, 2012a).

The method by which industries were allocated to an appropriate (generally high or low) exposure level is described by Van Tongeren *et al* (2012), and the use of the data in the estimation of cancer is described in the statistical methodology paper (Hutchings and Rushton, 2012).

Abbreviations: CAREX = CARcinogen Exposure Database; DEE = diesel engine exhaust; ETS = environmental tobacco smoke; LFS = Labour Force Survey; NHL = non-Hodgkin's lymphoma; REP = risk exposure period; TCDD = 2,3,7,8-tetrachlorodibenzo-*para*-dioxin. ^aNumbers ever exposed over the long latency REP for twelve agents with the greatest exposed numbers in the industries; for TCDD and non-arsenical insecticides short latency REP estimates are shown in brackets (used for leukaemia, NHL, soft tissue sarcoma and multiple myeloma). ^bNumber of agents for which the risk in this industry was considered to be negligible (relative risk = 1) are shown in brackets. ^cWomen only. ^dBased on deaths. ^eETS. ^fCadmium, nickel. ^gBeryllium, cadmium, inorganic lead, nickel, silica.

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See Appendix for the members of the British Occupational Cancer Burden Study Group.

Table 1 Estimates of numbers ever exposed during the REP, attributable fractions (AFs), deaths and registrations for industries with at least 100 attributable cancer registrations

Industry sector	Number of agents included in AF estimate ^b	Carcinogenic agent/occupation												Attributable fraction ^d	Attributable deaths	Attributable cancer registrations
		Examples of total numbers ever exposed during the REP ^a (1000 s), based on data from:														
		CAREX						LFS								
		Solar radiation	Silica	DEE	ETS	Radon	Wood dust	Benzene	Mineral oils	Shift work ^c	TCDD	Non-arsenical insecticides	Painters			
Farming	5 (1)	470		7	6						1269 (1053)			0.04%	65	220
Total agricultural, hunting, fishing and forestry	6 (1 ^a)	498		8	6	31					1683 (1481)			0.06%	88	263
Iron and steel basic industries	17 (1)	11		5	9	7	1	2	129		240 (431)			0.06%	84	135
Manufacture of industrial chemicals	23 (3)		4	9	13	20	4	3			57 (26)	7 (7)		0.07%	99	116
Manufacture of instruments, photographic and optical goods	13 (5)		9	1	27	15	1		448					0.03%	49	206
Manufacture of machinery except electrical	18 (5)		93	18	128	105	28		40					0.06%	91	111
Manufacture of other chemical products	19 (3)		32	8	22	28	7	4						0.07%	103	119
Manufacture of transport equipment	19 (4)	312	37	15	115	62	41		15					0.10%	155	182
Metal workers	1 (0)								4244					0.19%	284	1252
Mining	10 (0)	57	85	72		1								0.15%	228	296
Non-ferrous metal basic industries	18 (0)	18	14	15		12	1	0		300 (125)				0.08%	119	156
Painters (not construction)	1 (0)												327	0.05%	79	102
Printing, publishing and allied industries	14 (5)	182	4	3	66	52	12							0.16%	243	282
Welders	2 (0)													0.10%	153	181
Total manufacturing industry, mining, quarrying, electricity, gas, water	38 (1 ^a)	1123	688	432	615	731	1018	16	4924		1400 (1093)	50 (28)	327	1.47%	2200	3909
Construction	16 (2)	1575	2040	484	124	96	1034							2.30%	3457	4668
Painters and decorators (construction)	1 (0)												922	0.17%	254	334
Roofers, road surfacers, Roadmen, paviments (construction)	1 (0)													0.00%	4	471
Total construction	18 (2 ^f)	1575	2040	484	124	96	1034						922	2.46%	3694	5439
Land transport	13 (2)	364	21	616	18	49	21	26						0.28%	414	497
Personal and household services	17 (2)	28		284	133	81		811	1011					0.37%	556	670
Public administration and defence	6 (1)	449		10	122	159								0.02%	31	273
Shift work	1 (0)									1954				0.37%	552	1957
Wholesale and retail trade and restaurants and hotels	9 (1)	368		56	721	537		183			41 (18)			0.14%	211	246
Total service industries	32 (5 ^g)	2322	53	1148	1537	1769	66	1031	1011	1954	41 (18)			1.30%	1955	4007
Total	42 (0)	5517	2781	2063	2282	2602	2149	1047	5936	1954	3124 (1112)	1733 (1508)	1249	5.11%	7675	13263

Figure 1 Total cancer registrations in the construction industry by carcinogenic agent/occupation, as a proportion of all occupation-attributable cancers.

RESULTS

Attributable fractions (AF) and the total number of attributable cancer deaths and registrations for each main industry group and by industry sector for industries with at least 100 attributable cancers per year are summarised in Table 1. A more detailed breakdown of the number of attributable cancer registrations by industry sector and by (i) carcinogen or occupational circumstance and (ii) by cancer site are given in the tables within each main industry group below, and in full in the overview report (HSE, 2012a). The cancer sites associated with each occupational exposure are listed in Table 2 of the introduction paper (Rushton, 2012).

The largest number of attributable cancer cases occurs in the construction industry, followed by the mining, manufacturing and utilities sectors, as well as service sectors, with the least number of cases of cancer occurring in the agricultural forestry and fishing sector (Table 1). These figures reflect

- the number of people employed and exposed to specific carcinogens in these sectors during the REP,
- the relative risks associated with the carcinogens, and also
- the numbers of carcinogens and exposure circumstances that were relevant to each industry sector, which in some cases were considerable.

For example, AFs were estimated for 18 carcinogens/exposure circumstances for the construction sector, 38 for the mining, manufacturing and utilities sectors, 32 for the service sectors and 6 for the agriculture, forestry and fishing sectors (Table 1).

The highest number of cancer registrations occurred because of shift work and in metal workers (exposure to mineral oils), in personal and household services sector (this sector includes repair trades, laundries and dry cleaning, domestic services, hairdressing and beauty), land transport and mining (exposure to diesel engine exhaust (DEE) from vehicles and machinery), the printing industry (lung cancer associated with exposure to mineral oils) and public administration and defence (non-melanoma skin cancer (NMSC) in outdoor workers including the armed forces). Farming is also well up the list with lung cancer, non-Hodgkin's lymphoma (NHL), leukaemia and brain cancer due to past pesticide exposure, as well as NMSC from outdoor work in the sun. However, asbestos continues to be the greatest cause of occupational cancer, especially in construction.

The number of workers estimated to have been ever exposed over the REP to some of the main occupational carcinogenic agents found in these industries are also shown in Table 1. The highest numbers based on LFS data are metal workers (>4 million potentially exposed primarily by inhalation of metal working fluid mists) and motor mechanics (>1 million primarily exposed by the dermal route) exposed to mineral oils. Over 2 million employees were exposed to respirable crystalline silica (RCS) in the construction industry (based on CAREX data), nearly 2 million female night-shift workers were exposed to a possible risk of breast cancer and 1.3 million farmers and farm workers had past exposure to dioxin-contaminated (and non-arsenical) pesticides.

Agriculture, forestry and fishing

Table 2 summarises the occupation-attributable cancer registrations for the agriculture, forestry and fishing sectors by carcinogen/exposure circumstance and by cancer site. Past exposure to non-arsenical insecticides is estimated to be causing >70 cancers (NHL, leukaemia, brain cancer and multiple myelomas) a year and dioxin (TCDD) contamination >50 lung cancers a year.

Exposure to the sun is also an important potential carcinogenic exposure in agriculture, resulting in about 130 NMSCs. About 1.7 million people have been exposed to non-arsenical insecticides and dioxins in these sectors, and nearly 500,000 to solar radiation.

Mining, manufacturing and utilities

Tables 3 and 4 summarise occupation-attributable cancer registrations for the mining, manufacturing and utilities industries that are responsible for at least 10 attributable cancers a year, by carcinogen/exposure circumstance and by cancer site, ordered by industries associated with the most attributable cancers and the exposures (Table 3) and cancer sites (Table 4) involved.

The largest number of occupation-attributable cancer registrations in this sector (Table 3) were found among metal workers, in mining, printing, publishing and allied trades, as well as manufacture of instruments, photographic and optical goods.

Table 4 gives attributable registrations by cancer site and industry sector. The largest number of registrations were

Table 2 Estimated number of cancer registrations attributable to work in agriculture and forestry, by cancer site and carcinogenic agent

Industry sector	Carcinogenic agent												Overall	
	Non-arsenical insecticides					Radon	Solar radiation	TCDD		Wood dust				
	Cancer site													
	Brain	Leukaemia	NHL	MM	Total	Lung	NMSC	Lung	STS	Total	Sinonasal	Nasopharynx		Total
Farming	8	13	22	7	51	1	128	40	1	41				220
Forestry	0	1	1	0	2	0	7	1	0	1	1	0	1	11
Horticulture	3	5	8	3	19			12	0	13				31
Total ^a	11	19	31	10	72	1	135	54	1	55	1	0	1	263

Abbreviations: MM = multiple myeloma; NHL = non-Hodgkin's lymphoma; NMSC = non-melanoma skin cancer; TCDD = 2,3,7,8-tetrachlorodibenzo-*para*-dioxin; STS = soft tissue sarcoma. 0 = estimate <0.5. ^aTotals across exposures are estimated as the product sums of the attributable fractions and are not therefore equal to the sums of the separate estimates of registrations for each agent. Sums across cancers occasionally also differ owing to rounding error.

associated with cancers of the lung, NMSC, bladder cancer, mesothelioma and sinonasal cancer. Apart from mesothelioma, these cancers reflect exposures to mineral oils, particularly among metal workers and in the printing, publishing and allied industry sectors (98% were lung cancers), as well as among those involved in the manufacture of instruments, photographic and optical goods, where the cancers most frequently occurring were NMSC, bladder and lung cancers. Asbestos exposure was responsible for the second largest number of cancer registrations (357 lung cancer registrations, 168 mesotheliomas, 8 stomach cancers, 1 laryngeal cancer) in many of the manufacturing sector industries, including mining (180 lung cancer registrations, 9 mesotheliomas, 4 stomach cancers) and manufacture of transport equipment (60 lung cancer registrations, 54 mesotheliomas, 1 stomach cancer). Other parts of this industry where asbestos was estimated to have caused cancers included the manufacture of industrial (or other) chemical products, the electricity, gas and steam energy industry, manufacture of paper and work in petroleum refineries. These accounted for 43% of the remaining cancers attributed to asbestos exposure in these industries. It should be noted that, although overall asbestos-related lung cancers have been estimated on the evidence of a 1:1 ratio with mesothelioma (Hutchings and Rushton, 2012), allocation between industry sectors has been carried out proportionately according to AFs estimated on relative risks for high and low exposure of 1.48 and 1.18 for lung cancer and 7.3 and 1.1 for mesothelioma, respectively. The contrasting high/low differentials have resulted in different estimates of attributable mesotheliomas and lung cancers within industry sectors, with relatively low numbers of mesotheliomas in some sectors compared with the lung cancer estimates, especially for mining and also for personal and household services.

Exposure to dioxins also accounted for a large number of cancers across these sectors of industry (156 lung cancer registrations, 73 NHL, 25 soft tissue sarcomas (STS)), mostly occurring in the iron and steel industry (30 lung cancer registrations related to TCDD and an additional 29 estimated separately for steel foundry workers, 34 NHL, 12 STS), non-ferrous metal basic industries (37 lung cancers registrations, 10 NHL, 3 STS), glass and glass products industry (27 lung cancer registrations, 12 NHL, 4 STS) and manufacture of pottery, china and earthenware (23 lung cancer registrations, 9 NHL, 3 STS).

There were an estimated 200 lung cancer registrations caused by exposure to RCS, of which 43 were associated with the manufacture of non-metallic mineral products and 38 with the manufacture of pottery, china and clay.

Other exposures, which accounted for >100 registrations among those working in the mining, manufacturing and utilities sectors, included occupation as a welder (175 lung registrations), solar radiation (163 NMSCs), strong inorganic mists containing sulphuric acid (76 lung and 45 larynx cancers), arsenic (113 lung cancers) and work as a painter (67 lung, 19 stomach and 16 bladder cancers). Together, these nine exposures accounted for 87% of the registrations recorded among those working in manufacturing industry, mining, quarrying, electricity, gas and water industries.

For some of the industries within the manufacture and mining sectors, workers were exposed to a large number of carcinogens, with cancers occurring across a wide range of sites. Most notable are the manufacture of industrial chemicals and other chemical products (20 and 16 separate exposures with raised carcinogenic risk, respectively), involving cancers at 14 and 11 separate sites, respectively, although, as previously noted, lung (half due to asbestos) and mesothelioma cancer registrations predominated. Workers in the non-ferrous metal industry were exposed to 18 separate carcinogens (13 cancer sites) and in transport equipment manufacture 15 separate agents (12 cancer sites), although again dominated by asbestos exposure.

Construction

Overwhelmingly, the largest number of occupation-attributable cancers occurred in the construction industry, with a total of 5408 cancer registrations in 2004 and 3668 deaths in 2005, that is, 41% (48%) of total occupation-attributable cancers. Figure 1 shows the exposures associated with work in the construction industry and Table 5 shows occupation-attributable cancer registrations by carcinogenic agent or occupational circumstance and cancer site. On the basis of CAREX data, very large numbers are estimated to have been exposed to carcinogens in the construction sector (Table 1), 2 million to RCS, 1.6 million to solar radiation through outdoor work and nearly 500,000 to DEE. Labour Force Survey 1979 data also highlighted the large number of people

Table 3 Estimated numbers of cancer registrations attributable (> 10 registrations) to work in mining, manufacturing, electricity gas and water supply sectors, by industry and carcinogenic agent/occupational circumstance ranked by total number of registrations

Industry sector	Carcinogenic agent/occupation																				Other agents with < 10 registrations ^c	
	Mineral oils	Asbestos ^a	TCDD	Silica	Welders	Solar radiation	Strong inorganic-acid sulphuric acid	Arsenic	Painters	Chromium VI	DEE	Cobalt	Radon	Tetrachloroethylene	Aromatic amines	Inorganic lead	Leather dust	Steel foundry workers	Wood dust	Formaldehyde		Overall ^b
Metal Workers	1252																				1252	
Mining		192		29		31					43		0			0					296	IR, N, PAH, TM
Printing, publishing and allied industries	267					3				0	0	4	4	2					0		282	PAH
Manufacture of instruments, photographic and optical goods	203									0	0	2	1						0		206	Be, VCM
Manufacture of transport equipment		115		11		5	12	0		18	2	4	5	6					0		182	Be, N, PAH, Tri
Welders					175																181	UV
Non-ferrous metal basic industries			50	4		9	14	50		3	2	6	1	1		8			0	0	156	Bz, Ca, N, PAH, VCM
Iron and steel basic industries	0		75			0	3			0	0		1	1	16	2		29	0	0	135	Bz, PAH, PAHc
Manufacture of other chemical products		69		10			20	0		2	1	10	2			3			0	0	119	I-3B, Ac, Bz, EO, VCM
Manufacture of industrial chemicals		64	11	1			16	3		4	1	6	2		0	2			0	0	116	I-3B, Ac, Bz, Ca, NAP, PAH, VCM
Manufacture of machinery except electrical				28			13			28	2	5	9	18					0	0	111	Be, IR, PAH, Tri
Painters (not construction)									102												102	
Manufacture of pottery, china and earthenware			35	38		23	0			0		1	1	0							98	PAH
Manufacture of fabricated metal products, except machinery and equipment				14		1	17			26	2	11	4	13					0	0	94	Be, N, PAH, Tri
Electricity, gas and steam		19		6		53		1		0	2	0	2	3					0		88	Be, IR, PAH
Manufacture of other non-metallic mineral products			19	43		1		1		0	7	0	1						0	0	73	PAH, VCM
Manufacture of wood and wood and cork products, except furniture			14			2		35		0	2	2	2						8	1	66	PAH
Manufacture of glass and glass products			43	12		1		7		0	0	1	0	0					0	0	64	Be, PAH

Table 3 (Continued)

Industry sector	Carcinogenic agent/occupation																				Overall ^b	Other agents with < 10 registrations ^c
	Mineral oils	Asbestos ^a	TCDD	Silica	Welders	Solar radiation	Strong inorganic-acid mists containing sulphuric acid	Arsenic	Painters	Chromium VI	DEE	Cobalt	Radon	Tetrachloroethylene	Aromatic amines	Inorganic lead	Leather dust	Steel foundry workers	Wood dust	Formaldehyde		
Manufacture of paper and paper products		37	7				9			0	1	1	2	2					0	59	I-3B, PAH	
Manufacture of electrical machinery, apparatus, appliances and supplies							15	6		1	1	1	7	7		10			0	49	Be, Ca, Tri	
Petroleum refineries		38				7		0		0	0	0	0	0					0	46	I-3B, Bz, PAH, Petroleum refining, VCM	
Manufacture of furniture and fixture, except primary of metal								8		0	0	7	2						13	34	—	
Manufacture of textiles										0	1	0	3	3	23				0	31	—	
Water works and supply						26					2		0	0						29	—	
Manufacture of footwear										0			1				22		0	22	PAH	
Manufacture of leather and products of leather or of its substitutes							2			0		0	0	0	8		10		0	20	xLD	
Food manufacturing						1				0	2	4	6	2					0	15	EO, NAP, PAH, VCM	
Manufacture of plastic products not elsewhere classified										0	0	1	2		0	9			0	14	I-3B, Bz, VCM	
Manufacture of wearing apparel, except footwear						1				0	1	1	3	3					0	13	PAH, Tri, VCM	
Manufacture of rubber products										0		0	1		0	1			0	11	I-3B, Ac, PAH, Rubber industry	
Total manufacturing industry, mining, quarrying, electricity, gas, water	1722	535	254	200	175	163	122	113	102	86	80	67	62	60	48	34	31	29	23	11	3909	I-3B, Ac, Be, Bz, Ca, EO, IR, N, NAP, PAH, PAHc, Petroleum refining, Rubber ind., TM, Tri, UV, VCM

Abbreviations: Ac = acrylamide; Be = beryllium; Bz = benzene; Ca = cadmium; DEE = diesel engine exhaust; EO = ethylene oxide; IR = ionising radiation; LD = leather dust; N = nickel; NAP = non-arsenical insecticides; PAH = polycyclic aromatic hydrocarbons; PAHc = coal tars and pitches; TCDD = 2,3,7,8-tetrachlorodibenzo-p-dioxin; Tri = trichloroethylene; UV = ultra violet light (welders); VCM = vinyl chloride monomer; I-3B = I-3 butadiene. 0 = estimate < 0.5. ^aEstimates by industry for asbestos exclude mesotheliomas due to paraoccupational and environmental exposure. ^bTotals across exposures are estimated as the product sums of the attributable fractions and are not therefore equal to the sums of the separate estimates of registrations for each agent. Sums across industries occasionally also differ due to rounding error. ^cAgents for which the risk in these industry sectors was considered to be negligible (RR = 1) are omitted.

Table 4 Number of cancer registrations (> 10 registrations) attributable to work in mining, manufacturing, electricity gas and water supply sectors, by industry and cancer site, ranked by total number of registrations

Industry sector	Cancer site												Other sites with < 10 registrations
	Lung	NMSC	Bladder	Mesothelioma ^a	Sinonasal	NHL	Oesophagus	Larynx	Stomach	STS	Leukaemia	Total ^b	
Metal Workers	174	778	252		48							1252	
Mining	246	31	6	9					4		0	296	Bone (0), Brain (0), Liver (0), Thyroid (0)
Printing, publishing and allied industries	276	3	0		1		2					282	Brain (0), Cervix (0)
Manufacture of instruments, photographic and optical goods	32	125	44		6							206	Liver (0)
Manufacture of transport equipment	106	5	0	54	4	1	4	4	1			182	Cervix (1), Kidney (1), Liver (0)
Welders	175											181	Melanoma_eye (6)
Non-ferrous metal basic industries	124	9	1		1	10	0	5	3	3	0	156	Brain (0), Cervix (0), Liver (0),
Iron and steel basic industries	60	4	20		1	34	1	3	2	12	0	135	Brain (0), Cervix (0)
Manufacture of other chemical products	75		0	32	0			7	2		0	119	Brain (0), Liver (1), LH (0), Pancreas (0)
Manufacture of industrial chemicals	70		1	30	1	4		6	2	1	0	116	Brain (0), Liver (1), LH (0), MM (0), Pancreas (1)
Manufacture of machinery except electrical	81		0		5	2	14	5			0	111	Bone (0), Cervix (2), Kidney (1), Liver (0), Thyroid (0)
Painters (not construction)	67		16						19			102	
Manufacture of pottery, china and earthenware	62	23			0	9	0	0		3		98	Cervix (0)
Manufacture of fabricated metal products, except machinery and equipment	68	1	0		5	2	10	6			0	94	Cervix (1), Kidney (0), Liver (0)
Electricity, gas and steam	22	53	0	9	0		2	0	0		0	88	Bone (0), Cervix (0), Liver (0), Thyroid (0)
Manufacture of other non-metallic mineral products	64	1	2		0	4				1	0	73	Liver (0)
Manufacture of wood and wood and cork products, except furniture	52	2	0		6	2				1	1	66	Nasopharynx (3)
Manufacture of glass and glass products	48	1	0		0	12	0			4	0	64	Cervix (0), Nasopharynx (0)
Manufacture of paper and paper products	35		0	17	0		2	3	0	0	0	59	Cervix (0), LH (0)
Manufacture of electrical machinery, apparatus, appliances and supplies	32		0		1	1	5	5	3			49	Brain (0), Cervix (1), Kidney (0), Liver (0)
Petroleum refineries	20	7	0	18	0		0	0	0		0	46	Brain (0), Liver (0), LH (0)
Manufacture of furniture and fixture, except primary of metal	18		0		10						3	34	Nasopharynx (4)
Manufacture of textiles	3		23		1		2				1	31	Cervix (0), Nasopharynx (0)
Water works and supply	3	26	0				0					29	Cervix (0)
Manufacture of footwear	1				22							22	

Table 4 (Continued)

Industry sector	Cancer site												Other sites with <10 registrations
	Lung	NMSC	Bladder	Mesothelioma ^a	Sinonasal	NHL	Oesophagus	Larynx	Stomach	STS	Leukaemia	Total ^b	
Manufacture of leather and products of leather or of its substitutes	2		8		10		0	1				20	Cervix (0)
Food manufacturing	12	1	0		0		2				0	15	Brain (0), Cervix (0), Liver (0), MM (0)
Manufacture of plastic products not elsewhere classified	9		0		0				3		0	14	Brain (0), Liver (1)
Manufacture of wearing apparel, except footwear	4	1	0		1	0	3				4	13	Cervix (0), Kidney (0), Liver (0), Nasopharynx (1)
Manufacture of rubber products	1		0		0			3	6		0	11	Brain (0), LH (0), Pancreas (0)x
Total manufacturing industry, mining, quarrying, electricity, gas, water ^c	1958	1069	375	168	122	80	49	49	45	25	11	3909	Bone (0), Brain (1), Breast (0), Cervix (6), Kidney (2), Liver (4), LH (1), Melanoma_eye (6), MM (1), Nasopharynx (7), Ovary (0), Pancreas (1), Thyroid (0)

Abbreviations: LH = lymphohaematopoietic cancers; MM = multiple myeloma; NHL = non-Hodgkin's lymphoma; NMSC = non-melanoma skin cancer; STS = soft tissue sarcoma. ^aEstimates by industry for asbestos exclude mesotheliomas due to paraoccupational and environmental exposure. ^bTotals across cancers occasionally differ owing to rounding error. ^cTotal attributable cancer registrations for industries/occupational circumstances not included in the above table: crude petroleum and natural gas production (5), other manufacturing industries (5), beverage industries (4), manufacture of miscellaneous products of petroleum and coal (1), general industry (0), tobacco manufacture (0). 0 = estimate < 0.5.

employed as painters in the construction sector, as well as roofers, road builders and paviours who were exposed to coal tars and pitches. Exposure as a painter is linked to cancers of the bladder, lung and stomach; exposure to coal tars and pitches is linked with NMSC.

Asbestos is responsible for over half of the cancer registrations in construction and 70% of cancer deaths (2568 deaths, including 1249 lung cancers and 1292 mesotheliomas). Exposure to the sun while working outdoors (solar radiation) and to coal tars and pitches resulted in 1312 cancer registrations of NMSC, that is, 24% of all cancer registrations that are occurring in the construction industry.

Service industries

Tables 6 and 7 summarise occupation-attributable cancer registrations for the service sectors by carcinogen/occupational circumstance and by cancer site, respectively.

In the service sector, the highest numbers (> 1 million during the REP) were estimated to have been occupationally exposed to benzene and mineral oils, mainly in personal and household services (including vehicle repair and other repair services), and to DEE mainly in land transport (Table 1). About 2.3 million service sector workers have been exposed to a risk of NMSC from outdoor work in the sun, 1.8 million are at a risk of lung cancer from past exposure to radon and 1.5 million non-smokers are at a risk of lung cancer from environmental tobacco smoke (ETS) in the workplace. Very large numbers of women (nearly 2 million) have

worked as night-shift workers (breast cancer) in occupations associated with health care, transport, communication, leisure and hospitality sectors, as well as air transport. The percentage of women engaged in shift working has increased over the past two decades, with current estimates varying from under 5% in banking and finance to about 20% in transport and communication, and about one-third of female shift workers working in some form of night shift. Estimates were made separately for flight personnel (cabin crew and pilots) who are potentially exposed to ionising radiation, as well as night-work/time-zone shift work.

The largest number of occupation-attributable cancer registrations (93%) in this sector (Table 6) were associated with shift work (1957 registrations all associated with breast cancer); asbestos (428 lung cancer registrations, 141 mesothelioma, 4 stomach and 0 larynx, a total of 573 registrations), DEE (375 lung cancer registrations, 56 bladder, a total of 431 registrations), solar radiation (402 NMSC registrations), radon (137 lung cancer registrations) and ETS (123 lung cancer registrations). The largest number (96%) of cancer registrations in the service sector were associated with breast cancer, lung cancer, NMSC, mesothelioma and oesophageal cancer (Table 7).

Personal and household services, land transport and wholesale and retail trades, restaurants and hotels have > 150 cancer registrations (Table 6) in each industry, mostly asbestos-related and also because of DEE exposure in land transport and (historically) to ETS in the hospitality industry. Diesel engine exhaust in the transport-related sectors, as well as ETS and radon,

Table 5 Number of cancer registrations attributable to work in construction, by carcinogenic agent/occupational circumstance and cancer site

Carcinogenic agent/ occupation ^a	Cancer site													Overall ^b
	Lung	NMSC	Mesothelioma	Stomach	Bladder	Sinonasal	Oesophagus	Nasopharynx	Larynx	Brain	Leukaemia	Cervix	NHL	
Asbestos ^c	1438		1292	35					7					2773
Solar radiation		841												841
Silica	707													707
PAHs - coal tars and pitches		471												471
Painters	215			64	56									334
Diesel engine exhaust	249				41									290
ETS	36													36
Inorganic lead	20			11						1				31
Wood dust						21		8						29
Arsenic	15													15
Tetrachloro-ethylene							10					0		11
Radon	9													9
Cobalt	4													4
Chromium VI						0								0
Formaldehyde											0			0
Overall	2591	1302	1292	109	96	21	10	8	7	1	0	0	0	5439

Abbreviations: ETS = environmental tobacco smoke; NMSC = non-melanoma skin cancer; NHL = non-Hodgkin's lymphoma; PAH = polycyclic aromatic hydrocarbon. ^aChromium VI, cadmium, nickel are zero for lung cancer; formaldehyde is zero for sinonasal cancer; PAHs are zero for bladder cancer; tetrachloroethylene is zero for NHL as relative risks are set to 1 for low exposure levels to these agents in construction; 0 = estimate < 0.5. ^bTotals across exposures are estimated as the product sums of the attributable fractions and are not therefore equal to the sums of the separate estimates of registrations for each agent. Sums across cancers occasionally also differ owing to rounding error. ^cEstimates by industry for asbestos exclude mesotheliomas due to paraoccupational and environmental exposure.

produces relatively large numbers of lung and, in the case of DEE, bladder cancers across the service sector (Table 7). In personal and household services, cancer of the oesophagus, cancer of the cervix (women only) and NHL are associated with exposure to tetrachloroethylene in dry cleaning; cancer of the oesophagus is associated with exposure to soots in chimney sweeps (all men), and ovarian cancer (women only); bladder cancer and NHL are related to work as a hairdresser or barber. Public administration and defence also has a very large number of registrations, mostly because of NMSC (240) from sun exposure. Lung cancers from ETS and radon exposure are associated with office-based business employment in finance, insurance and other business services.

DISCUSSION

For most carcinogens, point estimates of numbers exposed within quite broadly defined industry sectors (SIC 68 2 and 3-digit codes) were available from CAREX. For agents not covered by CAREX, including carcinogenic exposures identified by occupational circumstance rather than a specific agent, the relevant occupations were identified as closely as possible from available national data sources, matching the jobs described in the published papers from which the relative risk estimates were obtained. It was assumed

that 100% of workers in these occupations were 'exposed'. In this context, it is notable that the exposures defined by occupation are high in the ranked list of industries/occupations based on both the numbers of attributable cancer registrations and estimates of the number of workers ever exposed; metal workers (exposed to mineral oils) and painters are examples (Table 1). Breast cancer in women attributed to shift (night) work is second only to asbestos in numbers of cancer registrations related to occupation. These occupation-based estimates, although estimated from the best available data, may therefore be over-estimates.

In some industry sectors, we have demonstrated that workers are exposed to a very wide range of carcinogenic agents, and a wide range in the numbers and types of cancers that can occur. This would suggest that an industry-based approach rather than an agent-based approach could help inform future research or strategies to reduce exposure and disease. Similarly, a cancer-based approach would be appropriate if it was thought that certain cancers were more amenable to prevention even where there may be more than one exposure circumstance causing these cancers. For example, on the basis of the large number of lung cancers attributable to exposure by the inhalation route, a strategy to focus on the use and performance of ventilation controls would be aimed at preventing most cancers of the respiratory tract. The results presented here facilitate comparison across the range of industry

Table 6 Estimated number of cancer registrations (> 10 registrations) attributable to work in the service sector, by industry and carcinogenic agent/occupational circumstance ranked by total registrations

Combined results by industry and exposure	Shift work	Asbestos ^a	DEE	Solar radiation	ETS	Radon	Tetrachloro-ethylene	Hairdressers and barbers	Soots	Aromatic amines	Flight personnel	Overall ^b	Other agents with < 10 registrations ^c
Shift work	1957											1957	—
Personal and household services		361	29	14	22	6	89	63	60	18		670	Bz, Ch, F, MWF, PAH, Tri
Land transport		133	350	6	3	4	3					498	Bz, Ch, IR, PAH, W
Public administration and defence			1	240	20	12						273	PAH
Wholesale and retail trade and restaurants and hotels		66	6	6	118	42						246	Bz, PAH, D
Sanitary and similar services		13	2	68	3	2						90	Ar, Bz, Ch, Co, IR, PAH, W
Recreational and cultural services				55	9	4						69	Ar
Financing, insurance, real estate and business services				3	33	26						63	Sr
Services allied to transport			33	3	6	1	0					43	Bz, Ch, Co, PAH, VCM, W
Education services					4	14	0			0		18	1-3B, Bz, F, VCM, W
Medical, dental, other health and veterinary services				1	11	14				0		18	1-3B, EO, F, IR
Flight Personnel					7						13	17	IR
Communication			3	5		3	0					16	W
Air transport			3			1	1					14	Ch, Co, F, PAH
Water transport			6	1	5	1	0					11	Bz, Ch, PAH, VCM, W
Welfare institutions				0	4	6						11	—
Business, professional and other organisation				1	1	1						3	ETS
Research and scientific institutes				1	1	1	0			0		3	1-3B, Ac, Bz, EO, ETS, F, IR, VCM
Total service industries	1957	573	431	402	248	137	94	63	60	18	13	4007	1-3B, Ac, Ar, Bz, Ch, Co, EO, F, IR, MWF, PAH, SIA, D, Tri, VCM, W

Abbreviations: Ac = acrylamide; Ar = arsenic; Bz = benzene; Ch = chromium VI; Co = cobalt; DEE = diesel engine exhaust; ETS = environmental tobacco smoke; F = formaldehyde; IR = ionising radiation; MWF = metal working fluids; PAH = polycyclic aromatic hydrocarbons; SIA = strong inorganic acid mists; Sr = solar radiation; Tri = trichloroethylene; VCM = vinyl chloride monomer; W = wood dust; 1-3B = 1-3 butadiene; 0 = estimate < 0.5. ^aEstimates by industry for asbestos exclude mesotheliomas due to paraoccupational and environmental exposure. ^bTotals across exposures are estimated as the product sums of the attributable fractions and are not therefore equal to the sums of the separate estimates of registrations for each agent. Sums across industries occasionally also differ owing to rounding error. ^cAgents for which the risk in these industry sectors was considered to be negligible (RR = 1) are omitted.

sectors where potential exposure to specific carcinogens occurs and could point the way to further investigation of the industrial processes involved.

The legacy of historical industrial exposures has contributed to the burden in the manufacturing industry sectors. However, an important finding from this study has been the relatively large

contributions of construction and the service sector to the overall burden of occupational cancer. In the service sector in particular, the agents involved are likely to be different from 'traditional' historical exposures. Construction especially stands out for its overall contribution, whether or not the share of asbestos-related cancer is included (40% including asbestos and 27% excluding

Table 7 Number of cancer registrations (> 10 registrations) attributable to work in the service sector, by industry and cancer site, ranked by total registrations

Industry sector	Cancer site										Other sites with < 10 registrations
	Breast	Lung	NMSC	Mesothelioma ^a	Oesophagus	Bladder	Ovary	NHL	Cervix	Total ^b	
Shift work	1957									1957	—
Personal and household services		349	14	65	125	36	33	28	11	670	Kidney (1), Leukaemia (5), liver (0), nasopharynx (0), stomach (2)
Land transport		377	6	62	3	48			0	498	Bone (0), larynx (0), leukaemia (1), liver (0), stomach (2), thyroid (0)
Public administration and defence		33	240			0				273	—
Wholesale and retail trade and restaurants and hotels		224	6	12		0		2		246	Leukaemia (1), STS (1), stomach (0)
Sanitary and similar services		19	68	2		0				90	Bone (0), leukaemia (0), liver (0), stomach (0), thyroid (0)
Recreational and cultural services		13	55							69	—
Financing, insurance, real estate and business services		60	3							63	—
Services allied to transport		36	3		0	4			0	43	Leukaemia (0), liver (0)
Education services		18			0	0			0	18	Leukaemia (0), liver (0), LH (0), nasopharynx (0)
Medical, dental, other health and veterinary services		16	1			0				18	Bone (0), leukaemia (1), liver (0), LH (0), nasopharynx (0), thyroid (0)
Flight personnel	13	12								17	Bone (0), leukaemia (0), liver (0), thyroid (0)
Communication		14	5		0	0			0	16	—
Air transport		1			1	0			0	14	Larynx (0), leukaemia (0), liver (0)
Water transport		11	1		0	0			0	11	Leukaemia (0), liver (0)
Welfare institutions		9	0							11	—
Business, professional and other organisation		2	1							3	—
Research and scientific institutes		2	1		0	0			0	3	Bone (0), leukaemia (0), liver (0), LH (0), nasopharynx (0), pancreas (0), thyroid (0)
Total service industries	1969	1195	402	141	129	90	33	29	11	4007	Bone (0), kidney (1), larynx (1), leukaemia (8), liver (1), LH (0), nasopharynx (0), pancreas (0), STS (1), stomach (4), thyroid (0)

Abbreviations: NMSC = Non Melanoma Skin Cancer; NHL = non-Hodgkin's Lymphoma; STS = Soft tissue sarcoma; LH = Lymphohaematopoietic cancers. ^aEstimates by industry for asbestos exclude mesotheliomas due to paraoccupational and environmental exposure. 0 = estimate < 0.5. ^bTotals cross cancers occasionally differ owing to rounding error.

asbestos). Occupational exposures in the service sector contribute the same proportion of attributable cancers (29%) as those in mining, manufacturing and utilities, the former being dominated by the emerging link between night-shift work and breast cancer and the latter being dominated by exposure to mineral oils. Other important carcinogens identified include DEE (service sector,

construction) and solar radiation (service sector and all outdoor work including in agriculture and defence).

Conflict of interest

The authors declare no conflict of interest.

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Appendix

British Occupational Cancer Burden Study Group

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