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Introduction

Occupational cancer burden in Great Britain

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A sound knowledge base is required to target resources to reduce workplace exposure to carcinogens. This project aimed to provide an objective estimate of the burden of cancer in Britain due to occupation. This volume presents extensive analyses for all carcinogens and occupational circumstances defined as definite or probable human occupational carcinogens by the International Agency for Research on Cancer. This article outlines the structure of the supplement – two methodological papers (statistical approach and exposure assessment), eight papers presenting the cancer-specific results grouped by broad anatomical site, a paper giving industry sector results and one discussing work-related cancer-prevention strategies. A brief summary of the methods and an overview of the updated overall results are given in this introductory paper. A general discussion of the overall strengths and limitations of the study is also presented. Overall, 8010 (5.3%) total cancer deaths in Britain and 13,598 cancer registrations were attributable to occupation in 2005 and 2004, respectively. The importance of cancer sites such as mesothelioma, sinonasal, lung, nasopharynx, breast, non-melanoma skin cancer, bladder, oesophagus, soft tissue sarcoma and stomach cancers are highlighted, as are carcinogens such as asbestos, mineral oils, solar radiation, silica, diesel engine exhaust, coal tars and pitches, dioxins, environmental tobacco smoke, radon, tetrachloroethylene, arsenic and strong inorganic mists, as well as occupational circumstances such as shift work and occupation as a painter or welder. The methods developed for this project are being adapted by other countries and extended to include social and economic impact evaluation.
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Doll and Peto (1981) estimated the proportion of cancer deaths in Britain due to occupational causes as 4% (with an uncertainty ranging from 2 to 8%), which equates to ~6000 deaths per annum (with a range of 3000–12 000). The aim of this project was to update the estimate of the burden of cancer in Britain due to occupation. This involved estimating the current overall attributable fractions (AF) and numbers of cancers due to occupation and the relative contribution of occupational carcinogens and carcinogenic processes. Evaluation was carried out for all carcinogenic agents and occupations classified by the International Agency for Research on Cancer (IARC) as a Group 1 (established) or 2A (probable) human carcinogens, and for which evidence of occupational exposure was either 'strong' or 'suggestive' for the specific cancer site (Siemiatycki *et al*, 2004; Rousseau *et al*, 2005; Straif *et al*, 2005; Straif *et al*, 2007).

The summary results from this project have been published previously in the BJC (Rushton *et al*, 2010), and this supplement provides more detail about the methodology, data and results for each cancer site. Complete technical reports covering these topics will be available on the Health and Safety Executive (HSE) website (http://www.hse.gov.uk/cancer/). The aim of this study has been to develop appropriate practical measures to reduce health risks to workers arising from exposure to carcinogens in the workplace. Identifying the number of workers exposed occupationally to carcinogens and the circumstances of these exposures are also key aspects of this study and are described in the methodology and exposure assessment papers in this supplement. The need for a sound baseline of evidence to inform future decision making by regulators is discussed in the final paper.

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STRUCTURE OF THE SUPPLEMENT

A brief summary of the methods and an overview of the updated overall results are given in this introductory paper together with a discussion of the overall strengths and limitations of the study. Two papers in this volume provide details of the methodology developed specifically for the project, a statistical methods paper followed by a paper describing the sources of available exposure data for the different carcinogens and the process of allocation of industry sectors to different levels of exposure. The cancer-specific results are presented in eight papers grouped by broad anatomical site; each paper gives a brief overview of the incidence, trends, occupational and non-occupational risk factors associated with the specific cancer, an overview of the literature reviewed for each carcinogen and the process of selection of appropriate data for burden estimation. One of the unique aspects of this study is the identification of occupations and industry sectors to target for risk reduction. Brief results were presented in our overview paper (Rushton *et al*, 2010). More detailed results for industry sectors highlighting the important ones defined by large numbers, multiple carcinogens and/or cancer sites are given in a separate paper in this

supplement. The last paper discusses work-related cancer-prevention strategies and how predictive science may help address the burden of occupational cancer in the twenty-first century.

METHODOLOGY

The primary measure of the burden of cancer used in this project was the AF, that is, the proportion of cases that would not have occurred in the absence of exposure; this was then used to estimate the attributable numbers (ANs; see Hutchings and Rushton (2012a), for more detailed statistical methods). The AF requires the risk of the disease due to the exposure of interest and the proportion of the target population exposed. Risk estimates, adjusted where appropriate for confounders, were obtained from key studies, meta-analyses or pooled studies, taking into account study quality. Dose–response risk estimates were generally not available in the epidemiological literature, nor were proportions of those exposed at different levels of exposure over time available for the working population in GB. However, where possible, risk estimates were obtained for an overall 'lower' level and an overall 'higher' level of exposure to the agents of concern and matched appropriately to the exposure scenario in question. The risk estimates used in the study are given in the overview technical report on the HSE website (HSE, 2012).

The period during which exposure occurred, which was relevant to the development of the cancer in the target year 2005, was defined as the risk exposure period (REP). For solid tumours, a latency of 10–50 years was assumed, giving a REP of 1956–1995; for haematopoietic neoplasms, a latency of 0–20 years was assumed, giving a REP of 1986–2005. The proportion of the population ever exposed to each carcinogenic agent or occupation in the REP was obtained from the ratio of the number of people ever exposed to the carcinogens of interest in each relevant industry/occupation within GB over the total number of people ever employed. National data were used to obtain these (see Van Tongeren *et al* (2012) for a more detailed account of the exposure aspects). Account was taken of changes in the number of people employed in the primary and manufacturing industry and service sectors in GB over the REP where appropriate, and adjustment was made for employment turnover over the period. Given the assumptions made about cancer latency and working age range, only cancers in patients aged 25 years and above in 2005/2004 could be attributable to occupation for the REP for long latency cancers, as well as cancers occuring in an age group of 15–79 for women and 15–85 for men for the REP for short latency cancers. National data sources such as the CARcinogen EXposure database (CAREX; Pannett *et al*, 1998), the UK Labour Force Survey (LFS, 2009) and Census of Employment (ONS, 2009) were used to estimate the number of people ever exposed over the REP.

OVERVIEW OF RESULTS

During the interval between publication of the overall results (Rushton *et al*, 2010) and production of this supplement, some minor corrections were made to several cancer site/exposure estimations. Table 1 therefore presents the updated results for the AFs and ANs, and Table 2 gives the number of cancer registrations by cancer site and ranked by carcinogen or occupational circumstance. The overall burden by cancer site (AFs, ANs and 95% confidence intervals) is given in Table 1. In all, 8.2% ($n=6355$) of cancer deaths in 2005 in men and 2.3% ($n=1655$) in women in Britain have been estimated to be due to occupation, giving an overall AF of 5.3% ($n=8010$). The combined AFs for registrations are 5.7% ($n=9988$) for men in 2004 and 2.1% ($n=3611$) for women, giving an overall AF based on registrations of 4.0% ($n=13{,}598$). The AFs are similar to those published before, but there are nine fewer deaths and the number of registrations is reduced by 81 (75 of which are in men; see footnotes in Table 2 for the reasons estimates that have changed). The changes occurred mainly in non-melanoma skin cancer due to exposure to polycyclic aromatic hydrocarbons (PAH) in coal tars and pitches where the update now excludes glaziers in the job category 'roofers and glaziers', which were included in error in the earlier estimation.

However, these amended results have not changed the conclusions from our previous publication. The most important cancer sites for occupational attribution are mesothelioma, sinonasal, lung and bladder cancers and non-melanoma skin cancer for men, and mesothelioma, sinonasal, lung, breast and nasopharyngeal cancers for women (Table 1). The agents responsible for most occupation-attributable cancers, each with over 100 attributable cancer registrations, are asbestos, shift work, mineral oils, solar radiation, silica, diesel engine exhaust, PAHs from coal tar and pitches, dioxins, environmental tobacco smoke encountered at work in non-smokers, radon exposure from natural exposure in workplaces, tetrachloroethylene, arsenic and strong inorganic acid mists, as well as occupation as a painter or a welder (Table 2).

DISCUSSION

Our estimate of the current burden in 2005 of occupation-related cancers of 5.3% translates to over 8000 cancer deaths in GB and is in contrast to the 212 deaths due to occupational injuries that occurred in 2005/06 (HSE, 2006). Burden estimates from other studies range between 3 and 10%, partly due to differences in the numbers of cancers and carcinogens considered. The study has identified several industry sectors and occupations with high numbers of attributable cancer deaths and registrations including construction, metal working, personal/household services, mining, land transport, printing/publishing, retail/hotels/restaurants, public administration/defence, farming and several manufacturing sectors (Hutchings and Rushton, 2012b). The construction industry and agriculture and farming together contributed 43% of the fatal injuries reported in 2005/06 (HSE, 2006), and our study adds to the work-related concerns in these industries, both of which also have the potential for increased risks from substances associated with respiratory diseases (Rushton, 2007).

The results presented in this supplement must be considered taking into account several uncertainties and limitations. Agents classified by IARC by the end of 2008 as Group I and 2A carcinogens were assessed. Other substances, such as IARC group 2B carcinogens, many of which may be treated as if they were human carcinogens in regulatory settings, have not yet been evaluated; our estimates could thus be too low. In addition, our estimates do not include evaluation of the results from the review and update by IARC of all Group 1 carcinogens carried out in 2009, in which a separate classification (potentially varying) was given for all cancer sites that were relevant to specific carcinogens. Our estimates are thus almost certainly an underestimate of the true burden.

The assumptions made in the methodology used for this study may have introduced uncertainty or bias in the estimates. For example, studies of British workforces were not always available from which to choose appropriate risk estimates; the study chosen may not have reflected exposures experienced in GB; and there may have been differences in distributions of confounders. However, it should be noted that the majority of risk estimates were obtained from meta-analyses, pooled studies or reviews. There was a paucity of available information on risk estimates for women, and for many carcinogens the risk estimates for men were used for women. In addition, most estimates were for mortality rather than for incidence. Epidemiological studies of occupational groups are often confounded by a 'healthy worker effect', that is, a reduced overall risk estimate compared with the general population. This, together with potential misclassification of exposure in epidemiological studies, could lead to an underestimation of the true effect and thus an underestimation of the burden.

Table 1 Estimated attributable fractions, deaths and registrations by cancer site in 2005 (deaths) and 2004 (registrations)

Cancer site		Attributable fraction (%) (95% confidence interval)			Attributable numbers (95% confidence interval)					
					Deaths (2005)[a]			Registrations (2004)		
	ICD-10 code	Male	Female	Total	Male	Female	Total	Male	Female	Total
Bladder	C67	7.1 (4.6, 9.7)	1.9 (1.3, 3.9)	5.3 (3.4, 7.7)	215 (139, 296)	30 (21, 62)	245 (159, 358)	496 (321, 684)	54 (37, 110)	550 (357, 795)
Bone	C40–C41	0.04	0.01	0.02	0	0	0	0	0	0
Brain	C70–C72	0.5 (0.1, 1.1)	0.1 (0, 0.2)	0.3 (0.0, 0.7)	10 (1, 20)	1 (0, 3)	11 (1, 23)	12 (1, 25)	2 (0, 4)	14 (1, 28)
Breast	C50		4.6 (3.3, 6.0)	4.6 (3.3, 6.0)		555 (397, 727)	555 (397, 727)		1969 (1407, 2579)	1969 (1407, 2579)
Cervix	C53		0.7 (0.0, 2.1)	0.7 (0.0, 2.1)		7 (0, 22)	7 (0, 22)		18 (1, 56)	18 (1, 56)
Kidney	C64–C66, C68	0.04 (0, 0.16)	0.04 (0, 0.14)	0.04 (0, 0.15)	1 (0, 3)	1 (0, 2)	1 (0, 5)	2 (0, 7)	1 (0, 4)	3 (0, 10)
Larynx	C32	2.9 (1.4, 5.7)	1.6 (0.6, 3.5)	2.6 (1.2, 5.2)	17 (8, 34)	3 (1, 6)	20 (9, 40)	50 (24, 99)	6 (2, 13)	56 (26, 112)
Leukaemia[a]	C91–C95	0.9 (0.2, 3.5)	0.5 (0.1, 4.5)	0.7 (0.1, 4.5)	18 (4, 71)	5 (1, 49)	23 (5, 120)	30 (7, 118)	9 (1, 80)	38 (8, 198)
Liver	C22	0.2 (0.1, 0.3)	0.1 (0.1, 0.2)	0.2 (0.1, 0.3)	4 (2, 6)	2 (1, 2)	5 (3, 8)	4 (2, 6)	1 (1, 2)	5 (3, 8)
Lung	C33–C34	21.1 (19.2, 24.7)	5.3 (4.3, 6.9)	14.5 (13.0, 17.2)	4020 (3659, 4696)	725 (592, 946)	4745 (4251, 5643)	4627 (4212, 5406)	815 (666, 1063)	5442 (4877, 6469)
LH	C81–C96	0.004 (0, 0.014)	0.002 (0, 0.007)	0.003 (0, 0.011)	0 (0, 1)	0 (0, 0)	0 (0, 1)	0 (0, 1)	0 (0, 0)	1 (0, 2)
Melanoma (eye)	C69	2.9 (0.6, 6.6)	0.4 (0.1, 1.0)	1.6 (0.3, 3.6)	1 (0, 3)	0 (0, 0)	1 (0, 3)	6 (1, 13)	1 (0, 2)	6 (1, 15)
Mesothelioma	C45	97.0 (96.0, 98.0)[b]	82.5 (75.0, 90.0)[b]	94.9 (93.0, 96.9)[b]	1699 (1681, 1717)	238 (216, 260)	1937 (1898, 1976)	1699 (1681, 1717)[c]	238 (216, 260)[c]	1937 (1898, 1976)[c]
MM	C90	0.4 (0, 1.0)	0.1 (0, 0.3)	0.3 (0, 0.7)	5 (0, 10)	1 (0, 2)	6 (0, 12)	8 (0, 18)	2 (0, 3)	10 (0, 21)
Nasopharynx	C11	10.8 (2.3, 47.9)	2.4 (0.6, 6.8)	8.0 (1.8, 34.3)	7 (2, 31)	1 (0, 2)	8 (2, 33)	14 (3, 61)	1 (0, 4)	15 (3, 65)
NHL	C82–C85	2.1 (0, 6.9)	1.1 (0.1, 2.9)	1.7 (0, 5.4)	43 (0, 138)	14 (1, 37)	57 (1, 176)	102 (0, 328)	39 (3, 101)	140 (3, 430)
NMSC[d]	C44	6.9 (1.3, 15.0)	1.1 (0.0, 2.9)	4.5 (0.8, 9.9)	20 (4, 44)	2 (0, 6)	23 (4, 50)	2513 (478, 5447)	349 (0, 899)	2862 (478, 6346)
Oesophagus	C15	3.3 (1.5, 7.5)	1.1 (0.3, 2.8)	2.5 (1.1, 5.9)	156 (70, 358)	28 (8, 70)	184 (78, 429)	159 (71, 365)	29 (9, 74)	188 (80, 439)
Ovary	C56		0.5 (0, 1.2)	0.5 (0, 1.2)		23 (0, 52)	23 (0, 52)		33 (0, 76)	33 (0, 76)
Pancreas	C25	0.02 (0, 0.07)	0.01 (0, 0.04)	0.01 (0, 0.05)	1 (0, 2)	0 (0, 1)	1 (0, 4)	1 (0, 2)	0 (0, 1)	1 (0, 4)
Sinonasal	C30–C31	43.3 (27.3, 74.0)	19.8 (14.4, 31.6)	32.7 (21.5, 54.8)	27 (17, 47)	10 (8, 16)	38 (25, 63)	95 (60, 162)	31 (23, 50)	126 (83, 212)
STS	C49	3.4 (0, 11.4)	1.1 (0, 3.8)	2.4 (0, 8.1)	11 (0, 36)	3 (0, 9)	13 (0, 45)	22 (0, 75)	4 (0, 15)	27 (0, 90)
Stomach	C16	3.0 (1.5, 5.1)	0.3 (0.1, 0.5)	1.9 (1.0, 3.4)	101 (52, 176)	6 (3, 11)	108 (55, 187)	149 (77, 258)	9 (4, 15)	157 (81, 274)
Thyroid	C73	0.12	0.02	0.05	0	0	0	0	0	1
Total:	**C00–C97**									
Based on deaths		**8.2 (7.2, 9.9)**	**2.3 (1.7, 3.2)**	**5.3 (4.6, 6.6)**	**6355 (5640, 7690)**	**1655 (1249, 2287)**	**8010 (6888, 9977)**			
Based on registrations		**5.7 (4.0, 8.4)**	**2.1 (1.4, 3.2)**	**4.0 (2.7, 5.9)**				**9988 (6938, 14,794)**	**3611 (2370, 5412)**	**13,598 (9308, 20,206)**
Total cancers in GB in ages 15+					**77,912**	**72,212**	**150,124**	**175,399**	**168,184**	**343,583**

Abbreviations: GB = Great Britain; ICD = International Classification of Diseases; NHL = non-Hodgkin's lymphoma; NMSC = non-melanoma skin cancer; STS = soft-tissue sarcoma. [a]Attributable fraction applicable to all leukaemias. [b]Includes cases described as due to paraoccupational or environmental exposure to asbestos. [c]Taken as equal to attributable deaths for this short survival cancer. [d]Based on registrations. Confidence intervals (CIs) were not estimated for bone and thyroid cancers, and other cancers attributed to ionising radiation, as CI estimates are not yet available for the excess relative risk models used (refer UNSCEAR report).

Table 2 Cancer registrations in 2004 attributable to occupation by exposure and cancer sites with at least 14 total attributable registrations

Carcinogen or occupation	Cancer site[a]																	Total attributable cancer registrations[b]
	Bladder	Brain	Breast	Cervix	Larynx	Leukaemia	Lung	Mesothelioma	Nasopharynx	NMSC	NHL	Oesophagus	Ovary	Sinonasal	STS	Stomach[c]	Other sites	
Asbestos					8		2223	1937								47		4216
Shift work (including flight personnel)			1957															1957
Mineral oils	296						470			902				55[d]				1730
Solar radiation										1541								1541
Silica							907											907
Diesel engine exhaust	106						695											801
PAHs: coal tars and pitches										475[e]								475
Painters	71						282									83		359
TCDD (dioxins)							215				74				27			316
Environmental tobacco smoke (non-smokers)							284											284
Radon							209											209
Welders							175											175
Tetrachloroethylene				18							17	130						164
Arsenic							129											129
Strong inorganic-acid mists containing sulphuric acid					46		76											122
Chromium VI							67							22				89
Non-arsenical insecticides		11				19					33						MM (10)	73
Cobalt							73											73
Inorganic lead[f]		2					42									23		67
Aromatic amines	66																	66
Hairdressers and barbers	15										14		33					63
Soots												60						60
Wood dust									14					39				54
Leather dust														31				31
Steel foundry workers							29											29
Formaldehyde[g]						10			1					1				12
Cadmium							9											9
Rubber industry					3											6		9
Nickel[h]							9							0				9
PAHs	7						1[i]											8
Beryllium							7											7
Trichloroethylene											3						Kidney (3) Liver (2)	7
Benzene						7												7
UV radiation (welders only)																	Melanoma-eye (6)	6
Ionising radiation						1	2										Bone (0) Liver (0) Thyroid (1)	4
Vinyl chloride																	Liver (3)	3
1,3-Butadiene						0											LH (1)	1
Acrylamide																	Pancreas (1)	1
Tin miners[j]							1											1
Ethylene oxide						1												1
Petroleum refining		0																0
Total registrations attributable to occupation	**550**	**14**	**1969**	**18**	**56**	**38**	**5442**	**1937**	**15**	**2862**	**140**	**188**	**33**	**126**	**27**	**157**	**26**	**13,598**
Total cancer registrations in GB (2004)[k]	**9878**	**3933**	**43,202**	**2612**	**2112**	**5202**	**37,378**	**2037**	**189**	**67,220**	**8236**	**7488**	**6197**	**378**	**1063**	**7970**	**22,034[l]**	**339,156[m]**

Abbreviations: GB = Great Britain; LH = lymphohaematopoietic malignancies; MM = multiple myeloma; NHL = non-Hodgkin's lymphoma; NMSC = non-melanoma skin cancer; PAH = polycyclic aromatic hydrocarbon; STS = soft-tissue sarcoma; TCDD = 2,3,7,8-tetrachlorodibenzodioxin; UV = ultraviolet.[a]Blank cells indicate that attributable cancer registrations were not estimated for this occupational exposure. Zero represents an estimate of <0.5.[b]Totals by cancer site are based on the product sums of the separate estimates of attributable fraction for each agent, and are not therefore equal to the sums of the separate estimates of attributable registrations for each agent. The difference is especially notable where the constituent attributable fractions and therefore attributable numbers are large.[c]Rubber industry now excluded from stomach cancer estimation to avoid double counting.[d]Printers and the dermally exposed industries now excluded from the sinonasal estimates for mineral oils.[e]Glaziers now excluded from job group 'roofers and glaziers'.[f]Printing industry now classified as low exposure rather than high.[g]Wood product industry now classified as low exposure rather than high.[h]Corrections made to the numbers exposed to nickel in the high exposed Clydach cohort.[i]Corrections made to the estimates for PAHs.[j]Corrections made to the numbers exposed in tin mining.[k]Registrations aged 25 years and above for solid tumours, and ages 15–84 for men, and 15–79 for women, for haematopoietic neoplasms. Figures for mesothelioma are based on deaths.[l]Includes bone, kidney, liver, melanoma (eye), MM, pancreas and thyroid.[m]All malignant neoplasms, ages 25 years and above (ICD 10th revision C00–C80) and 15–84/79 (ICD 10th revision C80–C97).

The approach to subdividing industry sectors into 'high' and 'low' exposure and allocating suitable risk estimates was a response to the lack of data on proportions exposed at different levels of exposure and the fact that many studies of occupational groups use relatively simple approaches to exposure assessment, for example, job titles. For most of the carcinogens considered, risk estimates in the source studies were related to some estimate of cumulative exposure. In assigning 'higher' and 'lower' categories to the industry groups for the calculation of the proportions exposed, e.g., using CAREX, implicit assumptions were made regarding the similarity of durations and intensities of exposure between the source and target (national) populations. Where no risk estimate could be identified for low levels of exposure, we estimated a relative risk (RR) based on harmonic mean of the high/low ratios across all other cancer–exposure pairs in the overall project where data were available; if the resulting RR estimate was <1, RR was set to 1. This may have led to inaccurate risk estimates for the low categories (either too large or too small). A substantial proportion of the ANs is likely to have resulted from a large number of workers with low exposures.

Our figures could have underestimated the number of workers 'ever exposed' in the REP because workers with <1 year of employment were not included in the analysis consistent with the exclusion of short term workers in many occupational epidemiological studies. Inclusion of these would have increased the numbers ever exposed considerably and hence increase the AFs and numbers.

There is a general paucity of information on latency of cancers due to occupational carcinogens, and hence we made pragmatic assumptions about the length of the latency period and hence the REP. This resulted in high estimates in some situations.

Work is ongoing to explore the sensitivity of the estimates to the sources of uncertainty and bias discussed above. An important aspect throughout this project was the involvement of international experts, including IARC, in advising on the methodology and interpretation of the results and peer reviewing the many technical reports. This supplement, together with the detailed technical reports on the HSE website, facilitates the transparent presentation of the methodology, data and results from this project. These methods have the potential to be adapted for use in other countries and extended to include social and economic impact evaluation. For example, the methodology and results contained in this study are informing an on-going estimation of occupational cancer for the Global Burden of Disease programme undertaken by the World Health Organisation.

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Conflict of interest

The authors declare no conflict of interest.

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