Full Paper

Occupational cancer in Britain
Industry sector results

Sally J Hutchings1 and Lesley Rushton*,1 with the British Occupational Cancer Burden Study Group

1Department 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, UK

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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-p-dioxin. Numbers 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). Number of agents for which the risk in this industry was considered to be negligible (relative risk = 1) are shown in brackets. Women only. Based on deaths. ETS. Cadmium, nickel. Beryllium, cadmium, inorganic lead, nickel, silica.
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 | CAREX LFS | Examples of total numbers ever exposed during the REP (1000 s), based on data from: |
|------------------------------------------------------|-----------------------------------------|-----------|-----------------------------------------------------------------------------------|
|                                                      |                                         | CAREX     | LFS                                                                 |
|                                                      |                                         | Silica    | DEE | ETS | Radon | Wood dust | Benzene | Mineral oils | Shift work | TCDD | Non-arsenical insecticides | Painters | Attributable fraction | Attributable deaths | Attributable cancer registrations |
| Farming                                              | 5 (1)                                   | 470       | 7   | 6   | 1269 | 1269 (1053) | 0.04%   | 65            | 220         |
| Total agricultural, hunting, fishing and forestry    | 6 (1+)                                  | 498       | 8   | 6   | 31   | 1683 (1481) | 0.06%   | 88            | 263         |
| Iron and steel basic industries                      | 17 (1)                                  | 11        | 5   | 9   | 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   | 1   | 407 (126) | 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      | 1   | 4244 | 1   | 1   | 4244 | 0.19%   | 284 | 1252 |
| Mining                                               | 10 (0)                                  | 57       | 85  | 72  | 1    | 1   | 1   | 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)                                   | 1         | 3   | 1   | 1   | 1   | 3   | 1       | 0.05% | 79   | 102 |
| Printing, publishing and allied industries           | 14 (5)                                  | 182      | 4   | 3   | 66   | 52  | 12  | 327 (79) | 0.16% | 243 | 282 |
| Welders                                              | 2 (0)                                   | 1         | 0   | 0   | 0    | 1   | 0   | 1       | 0.10% | 153 | 181 |
| Total manufacturing industry, mining, quarrying, electricity, gas, water | 38 (1+)                                  | 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)                                   | 1         | 3   | 1   | 1   | 1   | 1   | 922 (157) | 0.17% | 254 | 334 |
| Roofers, road surfacers, Roadmen, paviours (construction) | 1 (0)                                   | 1         | 3   | 1   | 1   | 1   | 1   | 922 (157) | 0.17% | 254 | 334 |
| Total construction                                   | 18 (2+)                                 | 1575     | 2040| 484 | 124  | 96  | 1034 | 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)                                  | 368      | 56  | 721 | 537  | 183 | 1   | 41 (18) | 0.14% | 211 | 246 |
| Public administration and defence                    | 6 (1)                                   | 284      | 133 | 81  | 811  | 1011 | 0.37% | 556 | 670 |
| Shift work                                           | 1 (0)                                   | 449      | 10  | 122 | 159  | 2   | 1   | 1       | 0.02% | 31   | 273 |
| Wholesale and retail trade and restaurants and hotels | 9 (1)                                   | 368      | 56  | 721 | 537  | 183 | 1   | 41 (18) | 0.14% | 211 | 246 |
| Total service industries                             | 32 (5+)                                 | 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 |
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 agriculture, 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...
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 differences in occupational attributable fractions 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 cancer 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 2

| Industry sector | Carcinogenic agent | 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         | Overall            | 8                         | 13     | 22  | 7  | 51    | 1    | 128  | 40   | 1   | 41    | 1         | 0          | 141   |
| Forestry        | Overall            | 0                         | 1      | 1   | 0  | 2     | 0    | 7    | 1    | 0   | 1     | 1         | 0          | 11    |
| Horticulture    | Overall            | 3                         | 5      | 8   | 3  | 19    | 1    | 12   | 0    | 13  | 31    | 1         | 0          | 40    |

Abbreviations: MM = multiple myeloma; NHL = non-Hodgkin’s lymphoma; NMSC = non-melanoma skin cancer; TCDD = 2,3,7,8-tetrachlorodibenzo-p-dioxin; STS = soft tissue sarcoma. 0 = estimate <0.5. *Totals 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.
### 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

| Carcinogenic agent/occupation | Industry sector | Metal Workers | Mining | Printing, publishing and allied industries | Manufacture of instruments, photographic and optical goods | Manufacture of transport equipment | Welders | Non-ferrous metal basic industries | Iron and steel basic industries | Manufacture of other chemical products | Manufacture of industrial chemicals | Manufacture of machinery except electrical | Painters (not construction) | Manufacture of pottery, china and earthenware | Manufacture of fabricated metal products, except machinery and equipment | Electricity, gas and steam | Manufacture of other non-metallic mineral products | Manufacture of wood and wood and cork products, except furniture | Manufacture of glass and glass products | Overall |
|-------------------------------|----------------|---------------|--------|---------------------------------------------|----------------------------------------------------|---------------------------------|--------|---------------------------------|--------------------------------|---------------------------------|---------------------------------|--------------------------------|-----------------------------|---------------------------------|---------------------------------|-----------------------------|-------------------------------|---------------------------------|---------------------------------|-----------------------------|
| Mineral oils                 | Mineral oils | 1252          | 192    | 267                                          | 203                                                | 203                             | 115    | 150                            | 0                             | 69                             | 64                              | 28                             | 35                           | 14                            | 19                            | 19                            | 14                            | 43                            | 14                             | 43                            | 12                            | 102                           | 1252                           |
| Asbestos                     | 29            | 43            | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                              | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                              | 0                             | 0                             | 0                              | 0                             | 0                              |
| TCDD                         | 31            | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                              | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                              | 0                             | 0                             | 0                              | 0                             | 0                              |
| Silica                       | 2             | 4             | 4      | 2                                            | 2                                                  | 2                               | 2      | 6                             | 1                             | 1                              | 1                               | 1                              | 1                            | 1                            | 1                              | 1                            | 1                             | 1                              | 1                             | 1                             | 1                              | 1                             | 1                              |
| Welders                      | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 1                             | 1                             | 1                              | 16                             | 2                             | 2                            | 2                             | 2                            | 2                             | 2                             | 2                             | 2                             | 2                             | 2                             | 2                             | 2                              |
| Solar radiation              | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Strong inorganic-acid mists  | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| containing sulphuric acid    | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Arsenic                      | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Painters                     | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Chromium VI                  | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Cobalt                       | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Radon                        | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Tetrachloroethylene          | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Aromatic amines              | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Inorganic lead               | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Leather dust                 | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Steel foundry workers        | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Wood dust                    | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Formaldehyde                 | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
| Other agents with < 10 registrations | 0             | 0             | 0      | 0                                            | 0                                                  | 0                               | 0      | 0                             | 0                             | 0                              | 0                               | 0                              | 0                            | 0                            | 0                              | 0                            | 0                             | 0                             | 0                             | 0                             | 0                             | 0                             | 0                              |
Table 3 (Continued)

| Industry sector | Carcinogenic agent/occupation | Other agents with <10 registrations |
|------------------|------------------------------|-----------------------------------|
| Manufacture of paper and paper products | Mineral oils | 37 | 7 | 9 | 0 | 1 | 1 | 2 | 2 | 0 | 59 | 1-3B, PAH |
| Manufacture of electrical machinery, apparatus, appliances and supplies | Asbestos | 15 | 6 | 1 | 1 | 1 | 7 | 7 | 10 | 0 | 49 | Be, Ca, Tri |
| Petroleum refineries | TCDD | 38 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 | 1-3B, Bz, PAH, Petroleum refining, VCM |
| Manufacture of furniture and fixture, except primary of metal | Silica | 8 | 0 | 0 | 0 | 2 | 13 | 3 | 34 | — |
| Manufacture of textiles | Welders | 26 | 2 | 0 | 0 | — | 29 | — |
| Water works and supply | Chromium VI | 0 | 1 | 0 | 3 | 3 | 23 | 0 | 1 | 31 | — |
| Manufacture of footwear | Radon | 0 | 1 | 0 | 22 | 0 | 22 | PAH |
| Manufacture of leather and products of leather or of its substitutes | Tetrachloroethylene | 2 | 0 | 0 | 0 | 8 | 10 | 0 | 20 | xLD |
| Food manufacturing | Aromatic amines | 1 | 0 | 2 | 4 | 6 | 2 | — | 15 | EO, NAP, PAH, VCM |
| Manufacture of plastic products not elsewhere classified | Inorganic-acid mists containing sulphuric acid | 0 | 0 | 1 | 2 | 0 | 9 | 0 | 0 | 14 | 1-3B, Bz, VCM |
| Manufacture of wearing apparel, except footwear | Inorganic lead | 1 | 0 | 1 | 1 | 3 | 3 | — | 5 | 13 | PAH, Tri, VCM |
| Manufacture of rubber products | Leather dust | 0 | 0 | 1 | 0 | 1 | 0 | 11 | 1-3B, Ac, PAH, Rubber Industry |
| Total manufacturing industry, mining, quarrying, electricity, gas, water | Overall | 1722 | 535 | 254 | 200 | 175 | 163 | 122 | 113 | 102 | 86 | 80 | 67 | 62 | 60 | 48 | 34 | 31 | 29 | 23 | 11 | 3909 | 1-3B, 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; 1-3B = 1-3 butadiene. 0 = estimate < 0.5. *Estimates 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. Agents 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* | Sponsal | NHL | Oesophagus | Larynx | Stomach | STS | Leukaemia | Totalb |
| Metal Workers                                        | 174 | 778 | 252 | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1252 |
| Mining                                               | 246 | 31 | 6 | 9 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 296 |
| Printing, publishing and allied industries           | 276 | 3 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 282 |
| Manufacture of instruments, photographic and optical goods | 32 | 125 | 44 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 206 |
| Manufacture of transport equipment                   | 106 | 5 | 0 | 54 | 4 | 1 | 4 | 4 | 1 | 0 | 0 | 182 |
| Welders                                              | 175 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 181 |
| Non-ferrous metal basic industries                   | 124 | 9 | 1 | 10 | 0 | 5 | 3 | 3 | 0 | 0 | 0 | 156 |
| Iron and steel basic industries                      | 60 | 4 | 20 | 1 | 34 | 1 | 3 | 2 | 12 | 0 | 0 | 135 |
| Manufacture of other chemical products               | 75 | 0 | 32 | 0 | 7 | 2 | 0 | 0 | 0 | 0 | 0 | 119 |
| Manufacture of industrial chemicals                  | 70 | 1 | 30 | 1 | 4 | 6 | 2 | 1 | 0 | 0 | 0 | 116 |
| Manufacture of machinery except electrical           | 81 | 0 | 5 | 2 | 14 | 5 | 0 | 0 | 0 | 0 | 0 | 111 |
| Painters (not construction)                          | 67 | 16 | 9 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 102 |
| Manufacture of pottery, china and earthenware        | 62 | 23 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 98 |
| Manufacture of fabricated metal products, except machinery and equipment | 68 | 1 | 0 | 5 | 2 | 10 | 6 | 0 | 0 | 0 | 0 | 94 |
| Electricity, gas and steam                           | 22 | 53 | 0 | 9 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 88 |
| Manufacture of other non-metallic mineral products   | 64 | 1 | 2 | 0 | 4 | 1 | 0 | 3 | 0 | 0 | 0 | 73 |
| Manufacture of wood and wood and cork products, except furniture | 52 | 2 | 0 | 6 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 66 |
| Manufacture of glass and glass products              | 48 | 1 | 0 | 0 | 12 | 0 | 4 | 0 | 0 | 0 | 0 | 64 |
| Manufacture of paper and paper products              | 35 | 2 | 0 | 17 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 59 |
| Manufacture of electrical machinery, apparatus, appliances and supplies | 32 | 0 | 1 | 5 | 5 | 3 | 0 | 0 | 0 | 0 | 0 | 49 |
| Petroleum refineries                                 | 20 | 7 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 |
| Manufacture of furniture and fixture, except primary of metal | 18 | 0 | 10 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 34 |
| Manufacture of textiles                              | 3 | 23 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 31 |
| Water works and supply                               | 3 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 |
| Manufacture of footwear                              | 1 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 |
employed as painters in the construction sector, as well as roofers, road builders and paviers 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,
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

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

Abbreviations: ETS = environmental tobacco smoke; NMSC = non-melanoma skin cancer; NHL = non-Hodgkin’s lymphoma; PAH = polycyclic aromatic hydrocarbon.

Chromium VI, cadmium, nickel are zero for lung cancer; formaldehyde is zero for sinonasal cancer; PAHs is 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. * Totals 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. ** Estimates by industry for asbestos exclude mesotheliomas due to paraoccupational and environmental exposure.
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 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 | DEE | Solar radiation | ETS | Radon | Tetrachloroethylene | Hairdressers and barbers | Soots | Aromatic amines | Flight personnel | Overall | Other agents with <10 registrations |
|-------------------------------------------|------------|----------|-----|----------------|-----|-------|---------------------|--------------------------|-------|----------------|----------------|---------|-----------------------------------|
| Shift work                                | 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             |     |       |                     |                          |       | PAH             | 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              |     |       |                     |                          |       | Ar              | 69            | Ar |
| Financing, insurance, real estate and business services | 3          | 33       | 26  |                |     |       |                     |                          |       | Sr              | 63            | Sr |
| Services allied to transport              | 33         | 3        | 6   | 1              | 0   |       |                     |                          |       |                 | 43            | Bz, Ch, Co, PAH, VCM, W |
| Education services                        | 4          | 14       | 0   |                |     |       |                     |                          |       |                 | 18            | 1-3B, Bz, F, VCM, W |
| Medical, dental, other health and veterinary services | 1          | 11       | 14  |                |     |       |                     |                          |       |                 | 18            | 1-3B, EO, F, IR |
| Flight Personnel                          | 7          |          |     |                |     |       |                     |                          |       |                 | 13            | IR |
| Communication                             | 3          | 5        | 3   | 0              |     |       |                     |                          |       | W               | 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   |                |     |       |                     |                          |       | ETS             | 3             | ETS |
| Research and scientific institutes        | 1          | 1        | 1   | 0              |     |       |                     |                          |       |                 | 3             | 1-3B, Ac, Bz, EO, ETS, F, IR, VCM |
| Total service industries                  | 1957       | 573      | 431 | 402            | 248 | 137   | 94                  | 63                       | 60    | 18              | 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. *Estimates by industry for asbestos exclude mesotheliomas due to paraoccupational and environmental exposure. **Totals 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. *Agents for which the risk in these industry sectors was considered to be negligible (RR = 1) are omitted.
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.

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 | Oesophagus | Bladder | Ovary | NHL | Cervix | Total |
| Shift work                                          | 1957   | —    | —    | —            | —         | —       | —     | —   | —      | 1957  |
| Personal and household services                     | 349    | 14   | 65   | 125          | 36        | 33      | 28    | 11  | 670    | —     |
| Land transport                                      | 377    | 6    | 62   | 3            | 48        | 0       | —     | —   | 498    | —     |
| Public administration and defence                   | 33     | 240  | 0    | —            | —         | —       | —     | —   | 273    | —     |
| Wholesale and retail trade and restaurants and hotels| 224    | 6    | 12   | 0            | 2         | —       | —     | —   | 246    | —     |
| Sanitary and similar services                       | 19     | 68   | 2    | 0            | —         | —       | —     | —   | 69     | —     |
| Recreational and cultural services                  | 13     | 55   | —    | —            | —         | —       | —     | —   | —      | —     |
| Financing, insurance, real estate and business services| 60     | 3    | —    | —            | —         | —       | —     | —   | —      | —     |
| Services allied to transport                         | 36     | 3    | 0    | 4            | —         | —       | —     | —   | 43     | —     |
| Education services                                  | 18     | 0    | 0    | 0            | —         | —       | —     | —   | —      | —     |
| Medical, dental, other health and veterinary services | 16     | 1    | 0    | —            | —         | —       | —     | —   | 18     | —     |
| Flight personnel                                    | 13     | 12   | —    | —            | —         | —       | —     | —   | 17     | —     |
| Communication                                       | 14     | 5    | 0    | 0            | —         | —       | —     | —   | 16     | —     |
| Air transport                                       | 1      | 1    | 0    | 0            | —         | —       | —     | —   | 14     | —     |
| Water transport                                     | 11     | 1    | 0    | 0            | —         | —       | —     | —   | 11     | —     |
| Welfare institutions                                | 9      | 0    | —    | —            | —         | —       | —     | —   | 11     | —     |
| Business, professional and other organisation       | 2      | 1    | —    | —            | —         | —       | —     | —   | 3      | —     |
| Research and scientific institutes                  | 2      | 1    | 0    | 0            | —         | —       | —     | —   | 3      | —     |
| Total service industries                            | 1969   | 1195 | 402  | 141          | 129       | 90      | 33    | 29  | 11     | 4007  |

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

British Occupational Cancer Burden Study Group

Lesley Rushton (PI)*,1, Sanjeev Bagga3, Ruth Bevan1, Terry Brown3, John W Cherrie4, Gareth S Evans2, Lea Fortunato1, Phillip Holmes3, Sally J Hutchings1, Rebecca Slack2, Martie Van Tongeren4 and Charlotte Young5.

1Department 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, UK; 2Health and Safety Laboratory, Harpur Hill, Buxton, Derbyshire SK17 9JN, UK; 3Institute of Environment and Health, Cranfield Health, Cranfield University, Cranfield MK43 0AL, UK; 4Institute of Occupational Medicine, Research Avenue North, Riccarton, Edinburgh EH14 4AP, UK; 5School of Geography, University of Leeds, Leeds LS2 9JT, UK.