Intervening to reduce the future burden of occupational cancer in Britain: what could work?

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Abstract

In Britain, 14 carcinogenic agents and occupational circumstances currently account for 86% of estimated occupation attributable cancer. The future burden associated with these carcinogens has been forecast, using attributable fractions for forecast scenarios representing patterns of past and predicted future exposure, and exposure levels representing the introduction of new occupational exposure limits, increased levels of compliance with these limits and other reductions in worker exposure. Without intervention occupational attributable cancers are forecast to remain at over 10,000 by 2060. With modest intervention nearly 2,500, or with stricter interventions over 8,100 cancers could be avoided by 2060 although due to long latency no impact will be seen until at least 10 years after intervention. Effective interventions assessed in this study include reducing workplace exposure limits and improving compliance with these limits. Cancers associated with asbestos, DEE, polycyclic aromatic hydrocarbons, work as a painter, radon and solar radiation are forecast to continue, with construction remaining the prime industry of concern. Although exposure levels to the established carcinogens are falling, workers are remaining exposed at low levels at which there is still a cancer risk, although the aging population also contributes to rising cancer numbers. These forecasts can be used to assess the relative costs to society of different occupational carcinogenic agents, and the relative merits and savings associated with alternative intervention strategies. The methods are adaptable for different data circumstances, other types of interventions and could be extended to environmental carcinogens and other chronic diseases.
We have estimated that 8% of cancers in men and 2.3% in women are caused by work, giving over 8,000 deaths and 13,600 cancer registrations in Great Britain (GB)(1) for all occupational carcinogens and occupational circumstances classified by the International Agency for Research on Cancer (IARC) as Group 1 (established) or 2A (probable) carcinogens that had either ‘strong’ or ‘suggestive’ evidence of carcinogenicity in humans (2).

The methodology has been extended to estimate the future burden of occupational cancer and to forecast the impact of alternative policy decisions affecting future workplace exposure levels (3). This paper presents estimates of the future burden of occupational cancer under a series of scenarios of change for 14 occupational carcinogens and circumstances in GB that each contribute at least 100 occupation attributable registrations to current burden and account for 86.3% of the total burden (Table 1).

MATERIALS AND METHODS

A full description of the methodology for estimating the current (4) and future burden (3) of occupational cancer can be found elsewhere. For our current burden estimation Levin’s formula was used to estimate the attributable fraction (AF), i.e. the proportion of cases due to occupational exposure (5, AF = p(E)*(RR-1)/{1+p(E)*(RR-1)} in its simplest form). This requires an estimate of the risk of disease, generally as relative risk (RR) which we obtained from published literature, and the proportion of the population exposed (p(E)), which we derived from national data sources, accounting for employment turnover and life expectancy, and adjusted for employment trends. To account for cancer latency a Risk Exposure Period (REP) was defined for each carcinogen as the exposure period relevant to a cancer appearing in a specific target year (10-50 years for solid tumours, 0-20 years for lymphohaematopoetic...
tumours). As exposure-response risk estimates and proportions exposed at different levels are not generally available, risk estimates and proportions exposed were obtained wherever possible for ‘high’, ‘medium’ and ‘low’ exposure levels with a ‘background’ level, where appropriate, assumed to have zero excess risk (these categories have been expanded from ‘high’ and ‘low’ only which were used to estimate current burden (1)). Estimated AFs were applied to total British deaths (for 2005) and registrations (for 2004) to give attributable cancer numbers.

To estimate future burden AFs were estimated for a series of forecast target years (FTY) i.e. 2010, 2020 … 2060 (3). A REP projected forward in time was defined for each FTY with the contribution of past exposure to future cancer risk decreasing for each FTY, see Figure S1. Adjustment factors were applied to newly recruited workers (assumed to be aged 15-24 years) in separate ten year estimation intervals to adjust for changing numbers employed in broad industry sectors, for example, an increase in the service industry sector and a decrease in manufacturing industry (based on Labour Force Survey data (6), Figure S2). Where data were available adjustment was also made for declining exposure levels (see Table S2 for estimated data on exposure levels and future annual declines in levels required for these adjustments to be made, plus Workplace Exposure Limits and current compliance levels to these limits. Full details of the method of adjustment can be found elsewhere (3)). Where suitable exposure data were not available, RRs could be adjusted to represent reduced risk scenarios, for example, excess risk was reduced successively by 25% per decade for painters, or workers could be shifted arbitrarily from higher to lower risk categories, for example, shift workers at risk of breast cancer were moved from longer to shorter duration of exposure.
For the current burden estimate for mesothelioma uniquely associated with asbestos exposure we used numbers directly from the UK register of mesotheliomas for 2005, as we believe this captures practically all cases in GB and is therefore more appropriate for use as a basis for burden estimation for this disease than our standard methods, which greatly underestimate current mesothelioma incidence. Asbestos related lung cancer was also estimated for current burden from mesothelioma register numbers using an assumption of a 1:1 ratio (1). We excluded only a small number (30-70 men and women a year in the UK) of background cases (spontaneous or from naturally occurring asbestos) from the register numbers. For future burden, we have allocated the current attributable mesotheliomas to three exposure levels, high and medium for occupational exposure and a low category for domestic exposure and environmental exposure believed to have been experienced by the post 1940s birth cohort and additional to the background rate (see footnotes to Table S1 for the details of the methodology).

Total AFs for cancer sites associated with multiple exposures have been estimated using the product equation \( AF_{\Sigma} = 1-\Pi_{i}(1-AF_{i}) \) for independent multiplicative estimates (7). To estimate attributable cancer numbers the forecast AFs were applied to an estimate of total cancers for that site based on current age-specific rates applied to GB population projections (Table S3). For mesothelioma however associated only with asbestos exposure recent projections based on past mortality rates were used (8).

Carcinogens and occupational circumstances included in the estimates

Table 1 gives the carcinogens and occupational circumstances from the current burden estimation for which future cancer burden was estimated, and the cancer sites that were affected. The carcinogens have been categorized as: (i) those for which no appropriate exposure measurements were available to use in standard setting; (ii) exposures defined by
occupational circumstance; and (iii) carcinogenic agents for which standards exist or can be set.

**Choosing scenarios**

Table S4 gives the scenarios tested for each carcinogen and occupational circumstance. Unless otherwise stated two baseline scenarios have been evaluated: baseline scenario 1 historic employment and exposure level trends until 2010, no change thereafter, and baseline trend scenario 2 historic and predicted employment and exposure trends included up to 2030, constant thereafter. Intervention scenarios have been compared to baseline 1.

For those agents where standards can be set the scenarios test the introduction of or reductions in current OELs and improved compliance to these standards. For arsenic and tetrachloroethylene the existing Workplace Exposure Limits (WELs), and for strong inorganic acid mists an earlier WEL, were much greater than estimated current average exposure levels (Table S2). For these and also for TCDD, the estimated boundary level between the two lowest exposure categories was used as a starting point for a possible exposure standard (Table S1). For TCDD the low/background boundary was used, representing a threshold below which excess risk for the agent was zero (background exposed). No such threshold is generally recognized for genotoxic carcinogens, so the high/low or medium/low boundary level was chosen for the other three substances.

For asbestos and diesel engine exhaust (DEE), no industries were categorized as background exposed with zero excess risk, so an estimate of the threshold level for background exposure was obtained from independent data. For DEE 0.001 mg/m³ as elemental carbon was chosen to reflect exposure levels in daily life, based on background urban and suburban exposure
measurements in Britain (12). For asbestos an upper boundary of 0.00001 f/ml was assumed for background exposure, based on urban exposure levels from which mesothelioma cases considered to be due to ‘background’ exposure may arise (13).

For occupational circumstances such as painters and welders, where no specified carcinogen has been identified, only a single RR was available. A decline in exposure level has therefore been assumed to translate linearly to a fall in excess risk. This approach was also adopted for dermal exposure to PAH in coal tars and pitches for which no exposure level RRs were available. For shift work, limits on the total time spent on night shifts over a lifetime were used as the intervention.

Where levels of exposure were not amenable to WEL setting, proportions of the exposed workers were moved to lower exposure categories (e.g. solar radiation) or a reduction in total numbers exposed (e.g. radon) was used in the forecasting. For environmental tobacco smoke (ETS), the effects of different levels of compliance to the current indoor smoking bans were tested.

RESULTS

Table 2 gives for all the carcinogens and occupational circumstances tested the attributable numbers of cancer registrations for 2010 and 2060 together with the numbers of cancer registrations avoided in 2060 for each of the scenarios in Table S4. Attributable cancer registrations are shown per year for each target year. Table S5 also gives AFs and combined results by cancer site across the 14 carcinogens or occupational circumstances. Full results can be found elsewhere (14).
As historic and forecast exposure levels decline, the AFs generally decline for baseline scenarios 1 and 2 to less than 1.5% of all cancer by 2060 (Table 2, and for example Figures 1(A)(i), 1(A)(ii) for DEE and lung cancer). However, for breast cancer associated with shift work, rising employment in service sector industries (Figure S2) leads to rising occupational AFs (Figure 1(B)(i)).

Predictions of total GB cancers taking account of only demographic changes leads to increasing attributable occupational cancer numbers because of the aging and increasing population (Figures 1(A)(ii) and 1(B)(ii)). Between 9,800 (scenario 2) and 10,400 (scenario 1) occupational cancers can be expected per year by 2060 from the baseline scenarios, not much lower than the numbers attributed to occupation in 2010. Breast cancer and non-melanoma skin cancer (NMSC) from sun exposure account for nearly 70% of these (Table 2).

Without new intervention strategies the numbers of cancers from low level exposure will continue to rise even though exposure levels are forecast to decline (scenario 2). Figures 2(a) and 2(b) illustrate this for lung cancer and DEE, where, although exposure levels are falling by an estimated 7.4% a year, substantial proportions of the population remain exposed at low levels of exposure which still carry a small excess risk (RR=1.1). Introducing an exposure standard of 0.1 mg/m$^3$ and assuming even 99% compliance does not improve on this (Figures 2(c) and 2(d), scenario 6a in Table S4). In contrast if an exposure standard could be introduced for DEE at the estimated level below which excess risk was zero, i.e. 0.001 mg/m$^3$ as elemental carbon (scenario 6, Figures 2(e) and 2(f)), lung cancers induced by DEE would nearly disappear by 2060 (Figure 1(A)(ii)). For this level of reduction however, technology driven intervention may be the only realistic solution.
Low level exposures will also continue to give high forecast numbers of asbestos related mesotheliomas for both baseline scenarios (62 in men and 200 in women for baseline trend 2) due to the increasing proportion exposed at low levels, even though a 13% annual reduction in average exposure levels has been assumed, and the mesothelioma projections used to estimate our forecast numbers have also taken falling exposure levels into account (8). However this is not the case for lung and the other asbestos related cancers as, in the absence of a suitable risk estimate, zero excess risk has been assumed other than for mesothelioma at this low (non-occupational) level. (Figures S3(a)-(f) and S3(g)-(l) show results for lung cancer and mesothelioma). Even if exposures could be reduced to the levels indicated by the strictest scenario (6) tested, i.e. to below 1/100th of the existing standard, some mesotheliomas remain in 2060 (60 men and 175 women), due to continued exposure at the level of additional background risk estimated for the 1940s birth cohort, above the low threshold at which it is believed excess risk will be zero (13). However, these forecasts do not take account of any change to the background risk among later birth cohorts. Our forecast mesothelioma estimates for women are higher than for men due to the higher relative risks for medium and low exposure used in their calculation (Table S1); they are given separately as we have less confidence in the results for women due to the small number of cases on which the risk estimates were based.

For solid tumour cancers for which long latencies are assumed, no difference is seen between any of the interventions and the baseline scenarios before 2030. The intervention scenarios were developed to be progressively more effective leading to progressive reductions in AFs and attributable cancers. Together the minimum interventions proposed in scenario 3 (the first and least restrictive scenario) would avoid nearly 2600 cancers a year by 2060, although only about 37 of these are for the chemicals (arsenic, acid mists, TCDD and...
tetrachloroethylene). The current (0.1 f/ml) standard for asbestos or a proposed (0.1 mg/m³) standard for DEE do not result in any 'avoided' cancers by 2060 (current compliance to these standards, shown in Table 1, exceeds 90%). For RCS an improvement in compliance to the 0.1 mg/m³ 8 hour TWA OEL from 33% to 90% could lead to nearly 700 fewer lung cancers annually by 2060 (Table 2). The number of cancers avoided increases as standards are tightened or exposure is progressively reduced (scenarios 4 and 5, Table 2).

The scenarios with the most extreme intervention (scenario 5 for most of the chemical agents; scenario 6 for asbestos and DEE, shift work and solar radiation, and for radon, painters, welders and coal tars and pitches) demonstrate how close to zero the attributable cancer numbers might realistically be expected to fall (Table 2). Numbers fall to zero only if an intervention results in all workers moving to exposure categories with zero excess risk e.g. achieving full compliance to no smoking in workplaces. Comparing the results for scenario 5, where excess risk has been reduced by 25% in successive decades for painters, welders and coal tars and pitches, and (6) where a halving of risk is achieved in the first decade, indicates the importance of early versus delayed intervention. Halving the proportions exposed in workplaces to radon in 2010 (scenario 6), for example by introducing appropriate technology, is far more effective than the gradual reduction shown in the other interventions. Similarly, achieving a reduction in risk from solar radiation to that associated with mixed indoor and outdoor exposure (RR=1.01, Table S1), e.g. using appropriate skin protection measures, removes most of the large numbers of predicted NMSCs. Restricting women to a maximum of five years on night shift work, for which the epidemiological evidence suggests excess risk is zero, would eliminate breast cancers attributable to this exposure (Figure 1(B)(ii)).
Our testing scenarios assume that compliance to exposure standards is less than 100%. Our results indicate that a large reduction in number of cancers can be achieved with 90% compliance to a current or proposed standard (scenario 3), and that 99% compliance (arsenic, RCS, strong acids, TCDD, tetrachloroethylene, scenario 6, DEE scenario 6a) only avoids an additional 107 cancers by 2060 (including 91 lung cancers from RCS exposure).

Forecasts for industry sectors with a current estimate (2004) (15) of over 80 attributable cancers are given in Tables 3 and S6. The ranking of the predicted cancers by industry sector in 2060 (scenario 2) remains similar to that in 2010 with construction remaining the most important industry sector for potential risk reduction targeting (21% in 2060), followed by three service industry sectors, and with breast cancer associated with night-shift work across all industry sectors also a leading contributor. By 2060 large numbers of workers are still projected to be exposed at low levels to the relevant carcinogens (DEE and asbestos, plus tetrachloroethylene in dry cleaners) in personal and household services and land transport. In land transport over two thirds, and in defence (armed forces) nearly all attributable cancers are forecast to be NMSCs due to high level (outdoor) sun exposure (Table S6).

DISCUSSION

Our results have demonstrated the potential for considerable eventual reduction in future occupationally-related cancers through a range of interventions, although the long legacy of past exposures will continue for up to 50 years. Even with the most stringent scenario tested, cancers are forecast to continue due to exposure to asbestos, PAHs as coal tars and pitches, work as a painter, exposure to radon and solar radiation, with construction remaining the prime industry of concern. Expected increases in cancer in general as the population ages contribute to the continuing high levels of some occupational cancers, and predicted increases
in numbers employed particularly in service sector industries also makes a contribution, for example to forecasts for shift work breast cancers, exposure to solar radiation, DEE and asbestos. In estimating the future burden of occupational cancer we have included the top 14 carcinogenic agents and occupational circumstances, which account for 86% of the estimated current burden of occupational cancer in Britain. Forecasts for agents currently contributing a further 1800 cancer registrations, including mineral oils, chromium VI, cobalt, aromatic amines and inorganic lead, non-arsenical insecticides, work as a hairdresser or barber, soots and wood dust exposure, and other agents currently responsible for fewer cancers in GB but classified by IARC as Group 1 carcinogens (including benzene, benzo(a)pyrene (PAH), beryllium, cadmium, formaldehyde, occupational exposure during iron and steel founding, leather dust, nickel compounds and rubber manufacturing) have not been included in the projection, but are equally important for cancer prevention. If these had been included, 14% more occupational attributable cancers (an additional 1600 a year) might be forecast (proportionately) by 2060 without intervention, with about 500 of these avoided with some minimum intervention as described for the estimated agents.

The contribution to the future total burden of large numbers of workers exposed at low levels within several service industries is highlighted, rather than the current more highly exposed manufacturing industry sectors, where interventions appear to be more effective in transferring workers from high to low exposed groups. For asbestos and DEE in particular, although exposure levels have been declining cancers still occur due to the low thresholds below which it is thought that excess risk disappears.

If numbers exposed from CAREX had been used to estimate cancer due to asbestos exposure, lung cancer would have been underestimated possibly 12 fold and mesothelioma 2 fold for
men and women compared to observed UK mesotheliomas (14). This suggests that numbers exposed to asbestos are underestimated by CAREX; our forecasts based on observed mesothelioma cases take this into account. CAREX-based estimates of numbers occupationally exposed, 1.2% of men and 0.2% of women, contrast with estimates of 65% of men and 23% of women based on the population controls in the UK study from which we have drawn risk estimates for mesothelioma (16).

It is also possible that the asbestos related lung cancer to mesothelioma ratio is higher than the 1:1 we have assumed. By estimating AFs on proportions exposed from the UK study and lung cancer relative risks, Table S1, there would be 5274 attributable lung cancers rather than 1709 in 2010 falling to 13 (not 5) in 2060 for baseline scenario 1. This would represent a current lung:mesothelioma ratio of about 3:1 in men and 6:1 in women. Similar ratios have been observed in asbestos exposed cohorts elsewhere (17). However using an alternative, lower estimate of the proportions exposed to asbestos (still higher however than the CAREX estimates), based on the mesothelioma attributable fractions derived from CAREX data and the relative risks in Table S1 but that have then been uprated to mesothelioma register numbers, gives more modest estimates, of 2002 attributable lung cancers in 2010 falling to 5 in 2060 for baseline scenario 1. This would represent a current lung:mesothelioma ratio of 1.2:1 in men and 0.3:1 in women.

Pragmatic approaches have been developed to take account of limitations in the data available for Britain. Alternative exposure levels or employment trends and different risk estimates could be used for other countries and situations and variations in existing standards can readily be explored.
Only limited intervention options were tested in this study, for example, reducing workplace limits and improving compliance with these limits. Many other potentially effective interventions have not been assessed, such as improving technology, increasing awareness, and changing attitudes and behaviours which are important in exposure control and risk reduction. Translating these interventions into testable scenarios is problematic; our solution has been to demonstrate the impact of the results that might be achieved, such as reduction in excess risk or shifts to lower exposure categories. We have shown that intervening to reduce exposure to workplace carcinogens could lead to the avoidance of over 8100 cancers per year by 2060. By comparison, with nearly 20% of all cancers (excluding NMSC) currently attributed to smoking (18), about an 8% immediate reduction in smoking levels would be required to avoid the same number of tobacco-related cancers. The removal of a workplace carcinogen entirely is of course the most effective possible intervention, by replacement with a less toxic or non-chemical means of fulfilling the same function, for example for tetrachloroethylene. In this case only the legacy of past exposures will remain.

The level of compliance to future OELs, i.e. the proportion of worker-exposures remaining above these limits, has also been tested. Full (100%) compliance cannot in practice be used with the lognormal distribution assumption and testing compliances approaching 100% gives unrealistically low results; as compliance approaches 100%, even though the standard may be well above the zero risk threshold, the distribution mean and proportions exposed above any zero risk threshold approach zero. In general, 90% compliance has been assumed to represent a realistically achievable target. Testing the timings of the introduction of standards and also the effect of different compliance levels in different industry sectors or sizes of industry has been explored. For RCS in Britain it has been shown that improvement in compliance in
small companies and among the self employed is more effective at reducing lung cancer than reducing the current standard (3).

Where the current standard was found to exceed the mean of current exposures by up to two orders of magnitude, testing values at a half or even a quarter of the standard does not really inform risk reduction strategies, as the estimated proportions exposed at high levels under the test scenario will unrealistically exceed the proportions exposed in the mid 1970s at those levels, leading to increased AFs and negative estimates of cancers ‘avoided’. Although this can be addressed by assuming compliance levels stricter than currently achieved estimates, we have tested standards that are less than the current estimated mean levels of exposure and therefore of more interest, although these may be difficult to achieve in practice.

If there are several risk factors contributing to the burden of a disease a change in attribution for one factor will result in a change in the attribution of the others. For example, if future smoking–related lung cancer falls giving a reduced non-occupational AF, the relative importance of occupation as a risk factor could increase leading to a rise in the occupational AF, although this AF would now be applied to lower projected lung cancer numbers. Attributable numbers rather than AFs therefore represent a more useful estimate of the future cancer burden due to occupation. In addition it is for this reason that estimated future occupational AFs have been applied to estimates of future cancer numbers based on current cancer rates applied to projected population estimates, ignoring future changes in other lifestyle or environmental risk factors. Cancer numbers attributable to occupation are then comparable by rank order between agents and industries. However the actual estimates may be considered to be inflated either (i) as the population is aging and numbers are increasing when employment levels and therefore exposed numbers are declining, or (ii) as other causal
factors decline so that occupational agents operating synergistically with an environmental or lifestyle factor (e.g. asbestos and smoking for lung cancer) produce fewer cancers. The effect is illustrated in Figure 3 for forecast lung cancers attributable to the exposures contributing at least 100 cancers (Table 1), estimated using cancer projections based on no change from 2005, demographic change only and increase to 2030 based on an age-period-cohort modelling approach (19).

All results presented here are subject to the biases to which our estimates of the current burden of occupational cancer are subject, described elsewhere (4). The most important of these are data-based, particularly relating to the matching of relative risks to our allocation of industries to exposure level categories, and the reliability of the data contributing to estimates of numbers ever exposed. Some re-allocation of industries between exposure categories has occurred between the estimation of current and future burden where additional categories have been introduced. In particular moving large numbers in construction and land transport from ‘high’ to a new ‘medium’ exposed category for DEE has resulted in much lower numbers of lung cancers attributable to DEE than estimated for current burden, as a reduced relative risk has been used for the medium exposed. For bladder cancer the current burden ‘high’ exposed RR was retained for this large group and a more specifically targeted higher RR has been used for the new and smaller high exposed group of miners and services allied to transport. Also, introducing a low ‘non-occupational’ category for asbestos exposure does reduce the forecast estimates for the asbestos-related cancers other than mesothelioma; as no risk estimates were available for this group, zero excess risk was assumed for the workers moving out of the higher occupational risk categories with our estimated annual fall in workplace exposure levels.
In summary, comparison of a range of interventions for the most important current occupational carcinogens has demonstrated the potential for future reduction of occupationally-related cancer. Interventions to reduce exposure to carcinogens may often also lead to reductions in other health related conditions in the working and living environment, e.g. reduction of silica exposure will not only reduce lung cancer but will affect respiratory function and other non-malignant respiratory diseases. Our methods can be adapted for different data circumstances, to investigate other types of interventions and could be extended to environmental carcinogens and other chronic diseases. Although the forecasts presented here are for Britain, the methods have been used to test the impact of introducing alternative exposure standards in the countries of the European Union for 25 chemical occupational carcinogens (20), and are readily transferable to other national and occupational settings.
Funding

The work was supported by the UK Health and Safety Executive (grant number JN 3117)

Acknowledgements: We thank the participants of the future burden methodology workshop, particularly Drs. John Hodgson, David Kriebel, Hans Kromhout, Damien McElvenny, Kyle Steenland, Kurt Straif and organizer Gareth Evans. The contributions and advice from the Health and Safety Executive and the rest of the project team is gratefully acknowledged, in particular Andy Darnton for his advice on the issues surrounding asbestos.

Conflict of Interest Declaration

The authors declare they have no conflict of interest.
REFERENCES


11. Health and Safety Executive Board. 3rd European Commission directive on Indicative Occupational Exposure Limit Values (IOELVs) – draft consultative document. 26th January 2011, HSE/11/05.


Table 1. Agents for which future burden has been estimated

<table>
<thead>
<tr>
<th>Exposure defined by agent; no appropriate exposure measurements available to use in standard setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental tobacco smoke (ETS)</td>
</tr>
<tr>
<td>Polycyclic aromatic hydrocarbons (PAH) as coal tars and pitches (men only)</td>
</tr>
<tr>
<td>Radon</td>
</tr>
<tr>
<td>Solar radiation</td>
</tr>
<tr>
<td><strong>Occupational circumstance</strong></td>
</tr>
<tr>
<td>Painters</td>
</tr>
<tr>
<td>Shift work (women only)</td>
</tr>
<tr>
<td>Welders</td>
</tr>
<tr>
<td><strong>Carcinogenic agents for which exposure standards can be set</strong></td>
</tr>
<tr>
<td>Arsenic</td>
</tr>
<tr>
<td>Asbestos</td>
</tr>
<tr>
<td>Diesel engine exhaust (DEE)</td>
</tr>
<tr>
<td>Respirable crystalline silica (RCS)</td>
</tr>
<tr>
<td>Strong inorganic acid mists</td>
</tr>
<tr>
<td>TCDD (dioxins)</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

¹ Mineral oils which account for a further 12.7% of attributable cancer registrations have been excluded as, due to the changes in the constituents of mineral oils that have occurred in the last few years, it was thought that the future cancer burden would already have been greatly reduced (9).

² This WEL was current in 2007 (10), but is currently under review (11). The estimated compliance indicated is to the WEL current in 2007.

³ Proposed new standard being considered by Scientific Committee on Occupational Exposure Limits (SCOEL).
Table 2. Total forecast cancers attributable to leading occupational carcinogens, 2060

| Exposure defined by agent; no appropriate exposure measurements available to use in standard setting | 
|---------------------------------------------------------------|---------------------------------------------------------------|
| **Exposure** | Attributeable Numbers of Cancer Registrations Avoided \(^{1}\) by 2060 |
| All | (1) | (2) | (3) | (4) | (5) | (6) |
| Cancer site | 2010 | 2060 | 2060 | 2060 |
| ETS Lung | 1465 | 0 | 0 | 67 | 156 | -67 | -156 |
| PAHs - Coal tars NMSC | 489 | 800 | 877 | 602 | 475 | 433 | 402 | 199 | 326 | 367 | 398 |
| Radon Lung | 220 | 379 | 411 | 341 | 317 | 309 | 190 | 38 | 62 | 69 | 189 |
| Solar radiation NMSC | 1749 | 3069 | 3279 | 2552 | 2030 | 1503 | 163 | 517 | 1039 | 1566 | 2906 |

**Occupational circumstance**

| Painters Bladder, Lung, Stomach | 461 | 640 | 639 | 481 | 380 | 347 | 321 | 159 | 260 | 293 | 319 |
| Shift work Breast | 1649 | 3062 | 3848 | 2134 | 1178 | 194 | 0 | 928 | 1883 | 2868 | 3062 |
| Welders Lung | 189 | 140 | 63 | 105 | 83 | 76 | 70 | 35 | 57 | 64 | 70 |

**Carcinogenic agents for which exposure standards can be set**

| Arsenic Lung | 128 | 92 | 47 | 90 | 88 | 87 | 87 | 1 | 4 | 5 | 5 |
| Asbestos Larynx, Lung, Mesothelioma, Stomach Bladder, Lung | 3876 | 259 | 263 | 255 | 255 | 253 | 253 | 4 | 4 | 6 | 24 |
| DEE \(^{3}\) Bladder, Lung | 380 | 406 | 399 | 451 | 412 | 374 | 34 | 0 | 0 | 31 | 371 |
| Silica Lung | 837 | 794 | 442 | 102 | 49 | 21 | 10 | 693 | 745 | 773 | 764 |
| Strong acids Larynx, Lung | 122 | 39 | 7 | 19 | 12 | 10 | 11 | 20 | 27 | 29 | 27 |
| TCDD Lung, NHL, STS | 282 | 8 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Tetrachloroethylene Cervix, NHL, Oesophagus | 139 | 135 | 119 | 123 | 118 | 117 | 119 | 12 | 17 | 18 | 15 |

**Total** | 11683 | 10357 | 9778 | 7303 | 5541 | 3719 | 1645 | 2590 | 4402 | 6060 | 8134 |

\(^{1}\) Relative to baseline scenario (1). Except for ETS, negative results, where the intervention has increased forecast cancer numbers (e.g. for DEE scenario (3) 90% compliance is lower than the current estimated compliance to the proposed standard), have been set to zero. All negative results are excluded from the total estimates.

\(^{2}\) Scenarios are as described in Table S4

\(^{3}\) Results in brackets for DEE are for the additional intervention scenario 6a
Table 3. Forecast cancers\(^{(1)}\) attributable to leading occupational carcinogens, by industry currently estimated with over 80 attributable registrations, ordered by baseline scenario (2) forecasts for 2060

<table>
<thead>
<tr>
<th>Industry /Occupation</th>
<th>Attributable numbers of cancer registrations</th>
<th>Scenario(^{(2)}):</th>
<th>2010</th>
<th>2060</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Construction</td>
<td>4700</td>
<td>2430</td>
<td>2190</td>
<td>1540</td>
</tr>
<tr>
<td>Painters and decorators (construction)</td>
<td>340</td>
<td>550</td>
<td>600</td>
<td>410</td>
</tr>
<tr>
<td>Roofers, road surfacers, Roadmen, Paviors (Construction)</td>
<td>480</td>
<td>790</td>
<td>870</td>
<td>600</td>
</tr>
<tr>
<td>Shift work (across all industries/occupations)(^{(3)})</td>
<td>1640</td>
<td>3040</td>
<td>3820</td>
<td>2120</td>
</tr>
<tr>
<td>Land transport</td>
<td>420</td>
<td>550</td>
<td>660</td>
<td>520</td>
</tr>
<tr>
<td>Public administration and defence</td>
<td>340</td>
<td>570</td>
<td>660</td>
<td>480</td>
</tr>
<tr>
<td>Personal and household services</td>
<td>400</td>
<td>230</td>
<td>240</td>
<td>230</td>
</tr>
<tr>
<td>Sanitary and similar services</td>
<td>90</td>
<td>160</td>
<td>190</td>
<td>140</td>
</tr>
<tr>
<td>Recreational and cultural services(^{(4)})</td>
<td>100</td>
<td>130</td>
<td>160</td>
<td>110</td>
</tr>
<tr>
<td>Wholesale and retail trade and restaurants and hotels</td>
<td>660</td>
<td>130</td>
<td>150</td>
<td>140</td>
</tr>
<tr>
<td>Farming</td>
<td>320</td>
<td>170</td>
<td>120</td>
<td>70</td>
</tr>
<tr>
<td>Financing, insurance, real estate and business services(^{(4)})</td>
<td>190</td>
<td>70</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Welders</td>
<td>190</td>
<td>140</td>
<td>60</td>
<td>110</td>
</tr>
<tr>
<td>Painters (not construction)</td>
<td>120</td>
<td>90</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>Mining</td>
<td>130</td>
<td>40</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Non-ferrous metal basic industries</td>
<td>80</td>
<td>40</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Manufacture of transport equipment</td>
<td>190</td>
<td>20</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Manufacture of industrial chemicals</td>
<td>100</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Manufacture of other chemical products</td>
<td>100</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

\(^{(1)}\) Totals may differ from main tables as agents are summed (product sums) separately by industry and other subgroups

\(^{(2)}\) Scenarios are as described in Table S4

\(^{(3)}\) Shift workers may be employed in all industries/occupations, but the cancer site involved (breast) does not overlap with cancer sites associated with other carcinogenic agents or occupations to which these workers may also have been exposed.
These industry sectors had less than 80 attributable registrations in the current burden estimates (2004), but are included as at least 80 are forecast for 2010. Iron and steel basic industries, manufacture of instruments, photographic and optical goods and of non-electrical machinery, metal workers and printing, publishing and allied industries had at least 80 current burden attributable registrations, but are excluded as these were predominantly due to exposure to mineral oils.
Figure legends

Figure 1. Results for baseline and intervention scenarios for (A) lung cancer attributable to DEE exposure (men plus women) and (B) breast cancer attributable to night shift work (women only), in terms of (i) attributable fractions and (ii) cancer registrations.

Figure 2. Proportions exposed to DEE and occupation attributable registrations for lung cancer assuming (a and b) linear employment trends and 7.4% annual exposure level decline to 2021-30, (c and d) introducing an exposure standard of 0.1 mg/m\(^3\) from 2010 with 99% compliance, and (e and f) introducing a much stricter exposure standard of 0.001 mg/m\(^3\) from 2010 with 90% compliance, by achieved exposure level in the forecast target year, men and women together.

Figure 3 Lung cancers in men due to occupational exposures, various cancer projections.
Figure 1A

(A)(i)

Baseline scenario (1): Current (2005) employment and exposure levels are maintained

Baseline scenario (2): Linear employment and exposure level trends assumed to 2021-30, constant thereafter

Intervention scenario (3): Introduce exposure standard=0.1 mg/m3 in 2010, 90% compliance

(A)(ii)

Intervention scenario (4): Introduce exposure standard=0.05 mg/m3 in 2010, 90% compliance, all workplaces

Intervention scenario (5): Introduce exposure standard=0.01 mg/m3 in 2010, 90% compliance, all workplaces

Intervention scenario (6): Introduce exposure standard=L/B boundary (0.001 mg/m3) in 2010, 90% compliance, all workplaces
Figure 1B

(B)(i)

- Baseline scenario (1): Current (2005) employment levels are maintained, workers assumed exposed in the proportions 30% for 15+ years, 40% 5-14 years, 30% <5 years duration of night-shift working.

- Baseline scenario (2): Linear employment trends assumed to 2021-30, constant thereafter, workers assumed exposed in the proportions 30% for 15+ years, 40% 5-14 years, 30% <5 years duration of night-shift working.

- Intervention scenario (3): Restrictions on length of employment result in 20% at 15+ years, 30% at 5-14 years and 50% at <5 years duration from 2010.

(B)(ii)

- Intervention scenario (4): Restrictions on length of employment result in 10% at 15+ years, 20% at 5-14 years and 70% at <5 years duration from 2010.

- Intervention scenario (5): Restrictions on length of employment result in 0% at 15+ years, 10% at 5-14 years and 90% at <5 years duration from 2010.

- Intervention scenario (6): 100% of workers restricted to <5 years duration from 2010.

Attributable Fraction

Attributable Cancers

Forecast year
Figure 2

(a) Baseline scenario (2): Linear employment trends and 7.4% annual exposure level decline assumed to 2021-30, constant thereafter

(b) Intervention scenario (6a): Introduce exposure standard=0.1 mg/m³ in 2010, 99% compliance

(c) Intervention scenario (6b): Introduce exposure standard=L/B boundary (0.001 mg/m³) in 2010, 90% compliance
Figure 3

[Graph showing attributable lung cancers over forecast years with different scenarios.]
Cancer Prevention Research

Intervening to reduce the future burden of occupational cancer in Britain: what could work?

Sally J. Hutchings, John W. Cherrie, Martie Van Tongeren, et al.


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