CAREX Canada: an enhanced model for assessing occupational carcinogen exposure

Cheryl E Peters,1,2 Calvin B Ge,2 Amy L Hall,1 Hugh W Davies,1 Paul A Demers3

ABSTRACT

Objectives To estimate the numbers of workers exposed to known and suspected occupational carcinogens in Canada, building on the methods of CARcinogen ExposuRE (CAREX) projects in the European Union (EU).

Methods CAREX Canada consists of estimates of the prevalence and level of exposure to occupational carcinogens. CAREX Canada includes occupational agents evaluated by the International Agency for Research on Cancer as known, probable or possible human carcinogens that were present and feasible to assess in Canadian workplaces. A Canadian Workplace Exposure Database was established to identify the potential for exposure in particular industries and occupations, and to create exposure level estimates among priority agents, where possible. CAREX Canada used expert assessment and agreement by a minimum of two occupational hygienists. These proportions were used to generate prevalence estimates by linkage with the Census of Population for 2006, and these estimates are available by industry, occupation, sex and province.

Results CAREX Canada estimated the number of workers exposed to 44 known, probable and suspected carcinogens. Estimates of levels of exposure were further developed for 18 priority agents. Common exposures included night shift work (1.9 million exposed), solar ultraviolet radiation exposure (1.5 million exposed) and diesel engine exhaust (781 000 exposed).

Conclusions A substantial proportion of Canadian workers are exposed to known and suspected carcinogens at work.

INTRODUCTION

The International Agency for Research on Cancer (IARC) has evaluated more than 900 agents and classified more than 400 as known or suspected carcinogens.1 Of these, 168 individual agents and 18 exposure situations (particular jobs or industries) are found in occupational environments.2 Accordingly, much epidemiological study of the carcinogenic properties of various agents occurs in occupational environments.3 Variations of this approach, such as Finnish job exposure matrix (FINJEM), which catalogues occupational exposure to a wide variety of hazards by over 300 occupations over time, have also been produced.4 FINJEM has been used for many purposes in Finland and beyond, including risk assessments, evaluating exposure trends and as a source for other JEMs.5 A Costa Rican version of CAREX (TICAREX) extended the original model by including estimates of occupational exposure by sex, as well as approaches to estimate exposure to pesticides in agriculture.6 The CAREX Canada project was founded in 2007 in an effort to create an enhanced and of knowledge of where carcinogenic exposures are occurring and how many workers are affected.7

Previous projects have attempted to address this knowledge gap. The CARcinogen ExposuRE (CAREX) surveillance system was developed by the Finnish Institute of Occupational Health, in collaboration with IARC and leading exposure assessment experts, as part of a larger project to estimate the burden of occupational cancer in Europe.6 The inputs to the CAREX system were developed by a team of international experts from across the European Union (EU). The EU CAREX included estimates of carcinogen exposure for 15 countries by 55 broad industry categories. The CAREX approach was also subsequently established in Estonia, Latvia, Czech Republic and Lithuania.7
Canadian-specific tool for occupational carcinogen exposure assessment. CAREX Canada’s occupational component is modelled after the EU CAREX project and was designed to incorporate the strengths of that system, as well as those of FINJEM. CAREX Canada also includes a component that is focused on environmental exposures, described elsewhere.11 The goal of CAREX Canada’s occupational component is to estimate the number of Canadian workers exposed to known and suspected carcinogens, and where possible, to estimate their levels of exposure.

Unique enhancements in the Canadian project include estimates of occupational exposure by detailed industry and occupation, as well as by sex and province. It is important in Canada to assess exposure by province because workplace health protection is largely administered at the provincial level, and providing exposure estimates at this level allows provinces to set their own priorities. The ability to separate estimates by sex is important for biological reasons (where an exposure leads to a sex-specific cancer) and expansion of CAREX estimates to other purposes (eg, estimating the burden of disease by sex). The CAREX Canada system also created and used a national exposure measurement database to produce estimates of occupational exposure, and the number of agents included was expanded to include more suspected carcinogens. This type of carcinogen exposure surveillance data can be used for the identification of high-risk groups, setting priorities for prevention-related activities, monitoring trends in exposure over time and assessing the impact of changing regulations.12 CAREX Canada does not include the primary collection of exposure data, but rather harvests from existing data sources to guide the exposure estimation process. The purpose of the present article is to highlight the enhancements made to the CAREX process in the creation of CAREX Canada, and summarise the occupational exposure estimate results (both exposure prevalence and level of exposure). This work was approved by the Research Ethics Board at the University of British Columbia.

**METHODS**

**Selection of carcinogens**

Known and suspected carcinogens were selected for inclusion in CAREX Canada (where the workplace was identified as a potential source of exposure) from the list of IARC-classified Group 1 (known human carcinogens), Group 2A (probable carcinogens) and Group 2B (possible carcinogens). The occupationally-related agents were then evaluated based on three criteria: (1) the agent was likely to be present in Canadian workplaces in the year 2006, and exposure was relatively prevalent (>10 000 likely to be exposed); (2) toxic effects, including carcinogenicity (IARC Group 1 agents were given higher priority); and (3) the feasibility of assessing exposure based on available data. Occupational exposure was defined as inhalation and/or dermal exposure at work to levels above environmental background levels. We combined some separate IARC agents into groups for exposure assessment when they were expected to be encountered together in workplaces. This grouping occurred for the polycyclic aromatic hydrocarbons and the antineoplastic agents.

**Data gathering**

A major component of the CAREX Canada occupational project was the creation of the Canadian Workplace Exposure Database (CWED), a repository of occupational exposure monitoring data from across Canadian jurisdictions. This database was used in two ways: (1) to identify the potential for exposure in particular industries and occupations and (2) to create exposure level estimates among the data-rich priority agents. At the time these estimates were developed, the CWED contained approximately 100 000 exposure measurements for known and suspected carcinogens collected between 1981 and 2004 for regulatory purposes in two of Canada’s largest provinces. The CWED has been continuously expanded as other Canadian provinces agree to contribute data, and at time of writing contained 460 000 measures of exposure (carcinogens and non-carcinogens).12 Other primary sources of data include the EU CAREX project (for proportions of workers exposed and other general methodology), published literature on exposure to carcinogens in the workplace, government reports and grey literature (figure 1). Population data on industry, occupation, province/territory and sex were obtained from Statistics Canada based on their 2006 Census of Population.13

**Occupational estimates approach and simple adaptations**

A generalised approach (outlined in figure 1) was developed to ensure comparability among substances, methodological transparency and ease of interpretation. This framework was flexible and was adapted for agents with unique data sources or particular assessment challenges.14 Primary data sources were reviewed
for relevance to the Canadian context and the proportion of workers likely to be exposed by industry and occupation in Canada was assigned using expert assessment and agreement by a minimum of two occupational hygienists. All procedures and estimates were externally reviewed by a scientific advisory committee composed of research and practice professionals in occupational hygiene and epidemiology.

These proportions were then linked to the census data to calculate a simple prevalence (number of workers exposed) by agent. Prevalence estimates were generated by industry (North American Industry Classification System or NAICS, 2002 version), occupation (National Occupational Classification—Statistics, 2006 version), province or territory, and sex.

Where data are available in the CWED, exposure levels were also estimated using a semiquantitative method based on the concepts used by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail in Quebec, Canada (IRSST). We used these criteria for exposure levels to match the methods and reporting structure of the IRSST because Quebec is the largest current exposure data collector in Canada, but these data were publically unavailable. Using their method allowed estimates to be comparable across jurisdictions. Two concentration thresholds were selected for each agent based on workplace exposure limits and cancer-relevant health outcomes. In general, we set high exposure thresholds to current threshold limit values from the American Conference of Governmental Industrial Hygienists (ACGIH), unless the limit was not set for cancer prevention reasons. In these cases (eg, for wool dust, where the current threshold limit value (TLV) is set to prevent non-malignant respiratory disease), we selected a threshold based on the epidemiological literature. We set the moderate thresholds as half of high exposure thresholds. For a given industry/job combination, high exposure was assigned when there were at least 25 samples available for that agent in a particular job and industry, and 20% or more of those samples had concentrations that were at or above the high threshold. The criteria for moderate exposure were met in one of two ways. Either (1) there were at least 25 samples available for that agent in a particular job and industry, and 20% or more of those samples had concentrations above the moderate threshold or (2) there were at least 10, but less than 25 samples, and 20% or more of those samples had concentrations above the high threshold. Workers were assigned into the low category of exposure where there were either no samples (but expert assessment deemed exposure as plausible) or the samples did not meet the criteria for moderate exposure (ie, were typically lower than half the exposure limit).

For some agents, CWED data were not available, but we were able to estimate exposure levels via some simple adaptations to the general framework. Two examples of this are artificial ultraviolet radiation (UVR) and solar UVR exposure to outdoor workers. Since there are no systematic measures of these physical hazards in Canada, we developed modified methods in order to assess both prevalence and level of exposure. The detailed methods and results of the solar UVR exposure assessment have been published elsewhere. Briefly, exposure categories were developed based on expected time spent outdoors. Groups were categorised as having high exposure when ≥75% of their workday was expected to be outdoors, and these jobs were identified using skin cancer prevention materials from Australian campaigns. For the moderate and low categories of exposure, Canadian career-selection websites were used to identify jobs with outdoor components.

To develop estimates of the levels of artificial UVR exposure, we used a report by the International Commission of Non-Ionizing Radiation Protection (ICNIRP). This report classified exposure to artificial UVR into categories of low, medium, high and very high with respect to the potential for overexposure. The only source classified with a low potential was exposure to general lighting, which CAREX Canada defined as environmental exposure (rather than occupational). Therefore, we excluded ICNIRP’s low potential for overexposure classification and defined our exposure groups based on their medium, high and very high potential for overexposure categories. A group of workers was considered to have low exposure if the ICNIRP found that there was a medium potential for overexposure, moderate exposure if the ICNIRP classified the job as having a high potential for overexposure and high exposure if the ICNIRP classified the job as having a very high potential for overexposure.

**Unique data sources: shift work, antineoplastic agents and ionising radiation**

It is relatively simple to adapt the generalised occupational estimates approach to other exposures that either a) are non-traditional from an industrial hygiene perspective or b) have unique challenges or exposure monitoring practices that make the general approach less desirable. The three main exposures where this occurred in CAREX Canada were shift work, ionising radiation and antineoplastic agents.

Briefly for shift work, we used Statistics Canada’s Survey of Labour and Income Dynamics public-use micro-data file for the year 2006. This survey was selected because it is a large, nationally representative survey that has information on industry and occupation for all respondents, as well as data on the type of shift that people work in Canada. Exposure was defined as regular work between the hours of 12:00 and 05:00, which was captured by the self-reported shift types of ‘A rotating shift’ and ‘Regular night or graveyard schedule.’ Population counts were calculated by using Statistics Canada provided weights for use in their survey data. The granularity of codes available for industry and occupation in the public-use micro-data file was less than that for census-derived exposure estimates. Therefore, in order to compare exposure estimates by industry, some basic assumptions were made, which are noted where applicable in the results tables.

For ionising radiation, we consulted complementary data available in the 2007 and 2008 annual reports from the National Dose Registry (NDR) in order to reconstruct exposure estimates for 2006. The NDR is a centralised Canadian registry of occupational radiation doses which contains records for over 100,000 currently monitored Canadians.

We calculated a range in the number of workers exposed to ionising radiation to account for uncertainties in how regulations are administered across different Canadian jurisdictions. The low end of the range is the number of monitored workers with a whole-body dose above the limit of detection (ranges from 0.1 to 0.2 mSv (millisievert)) over 1 year. The high end of the range is an extrapolation based on a detailed review of each NDR defined job title with respect to the number of workers likely to be missing from the population of monitored workers. We also examined the proportions of workers exposed from European CAREX projects where we were unable to estimate the proportion of exposed workers directly. For levels of exposure, workers were classified as having low exposure if their annual whole-body radiation dose was between the limit of detection and 1 mSv; moderate exposure if their dose was >1 to <20 mSv; and high if their dose was >20 mSv (which is also the ACGIH occupational exposure limit for an annual dose).
For antineoplastic agents, a varied expert-based approach was used depending on the job/industry being considered. Data sources included: (1) peer-reviewed literature, (2) human resources databases, (3) reports on industry practices, (4) unpublished reports on the potential for antineoplastic agent exposure and (5) personal communication with experts in academia and industry. Estimates were produced separately for hospital nurses and physicians, hospital pharmacy staff, community pharmacy staff and veterinary workers.

Data quality definitions
After we calculated prevalence and level of exposure estimates, we assigned a data quality score to each agent. We classified agents as having high quality data where we were able to produce quantitative estimates of the levels of exposure using at least 1000 CWED observations per agent across a variety of industries. An important limitation to this classification is that much of our data are over 10 years old. For agents where we had evidence of stable exposures over that time period (ie, silica), this is less of an issue; however, for agents like tetra-chloroethylene, where regulations have changed substantially in the last 5–10 years, we are less convinced that our historic data truly reflect current exposure in the workplace.

We classified agents as having moderate data quality when there were few data available, but where other proxy information on exposure allowed us to assign exposure levels. A good example of this situation is the antineoplastic agents, where few objective exposure measures are available since regulatory exposure monitoring does not occur in Canada. Moderate data quality was also assigned for substances with less than 1000 (but greater than 200) exposure data points available.

We classified agents as having low data quality where we had insufficient exposure data points (<200) to attempt to assign exposure levels, and also in the case of asbestos, where exposure situations have changed significantly in past decades so that assigning accurate exposure levels was difficult.

RESULTS
General results: prevalence and level of exposure, and data quality in Canada
Overall, CAREX Canada produced occupational prevalence estimates for 44 known and suspected carcinogens, and semiquantitative estimates of exposure levels for 18 of these agents. Table 1 outlines the results, categorised by IARC classifications. The data quality variable for each agent is also noted.

Overall, the most prevalent exposure in Canada was shift work (1.9 million exposed), followed by solar UVR exposure to outdoor workers (n=1.5 million), diesel engine exhaust (n=781 000) and benzene (n=374 000). In terms of data quality, 24 (55%) of the 44 agents had low quality data (not enough information to assign exposure levels, or data too outdated to use) and 8 (18%) had moderate data quality (200–1000 workplace samples in the CWED or good quality qualitative data on exposure levels). Only 12 of the agents reviewed (27%) were classified as having high quality data (quantitative exposure level estimates possible, with >1000 samples available in the CWED). More men than women were exposed to carcinogens; the mean percentage of men exposed by carcinogen was 79%, ranging from 27% for antineoplastic agents to 97% for polychlorinated biphenyls (see online supplementary table S1 for more details).

Results are shown in table 2 for the 18 agents where exposure level estimates were calculated. For most agents, the greatest proportion of exposure tends to be located in the low exposure category. However, agents such as solar radiation, wood dust and artificial UV radiation display large proportions of workers in the high category of exposure.

Exposure prevalence by two-digit NAICS 2002 industry codes is shown in table 3. The total number of workers employed in each industry is also presented, as well as the top three exposure agents (ordered by prevalence). The number of exposures column indicates occurrences of exposure as opposed to individuals exposed. Although one person may very well be exposed to more than one agent, the exposures-per-worker metric gives an indication of the overall prevalence of exposure to known and suspected carcinogens. The mining and oil and gas extraction industry (NAICS 21) along with the construction industry (NAICS 23) are two notable instances where the exposures-per-worker exceed 1.0.

By way of an illustration, table 4 shows the same information as table 3, focusing in a more detailed level on a single sector (manufacturing). This table does not include exposures from ionising radiation or shift work, since the industry classifications systems used for these agents were not available at a sufficient level of detail to link directly to the other estimates. Therefore, in many cases, one of these two exposures could be in the top three, but we cannot address this for the manufacturing industry. The exposures-per-worker metric here is highest in primary metal manufacturing and wood product manufacturing. A similar table with results presented by occupation (job title) is available in the online supplementary table S2. In addition, results for the 12 most prevalence exposures in Canada are presented by province in the online supplementary table S3.

DISCUSSION
CAREX Canada used a well-established model for exposure surveillance developed for and applied across the workforces of many countries in Europe5 and specifically Finland.8 We expanded on these models by modifying the programme to focus on the Canadian context (adding exposure estimation for many suspected carcinogens that were not initially included, updating proportions exposed to reflect variability in Canadian industries, etc). In addition, we used a more detailed set of labour force data, allowing us to examine exposure at a finer level of detail with respect to industry and occupation titles, as well as jurisdiction (province or territory), and sex. We also created and used a CWED to increase the accuracy and robustness of our exposure estimates. These enhancements together provide a repository of data and other information on occupational exposure to known and suspected carcinogens in Canada, and could serve as a model for expanding CAREX-type systems to other jurisdictions, particularly in the Americas. These enhancements could be applied in other countries with available labour force data, and could be improved further by the addition of age as a dimension in the system. We were not able to include age in our assessment because the extra dimension made some cells in the census data too small for release from Statistics Canada.

CAREX EU estimates of exposure have been used for other purposes, notably for estimating the burden of occupational cancer in various countries. For example, a recent study in the UK by Rushton et al used CAREX EU data to complete the exposure assessment portion of the project.23 CAREX Canada estimates are being used in a similar fashion in a study, currently underway, to estimate the burden of occupational cancer in Canada. Having country-specific estimates of exposure that use measured data is an improvement to burden studies that could be employed in the future.
Each substance was reviewed in detail by job and industry with potential exposure; design of assessment techniques and reporting of each exposure estimate was reviewed by a scientific advisory committee. Another feature of the CAREX Canada estimates is that they were developed using measured exposure data from Canada; a database created during this process is now being adapted and expanded to include other jurisdictions and non-carcinogenic substances of interest.

CAREX Canada’s estimates of exposure can be presented by any available dimension, including industry, occupation, province, sex and exposure level; this ability is a key enhancement to previous CAREX projects. The original platform for the European CAREX was strictly driven by a broad industry category, and so this system increases flexibility of use. The CAREX Canada system defines exposure very broadly (any exposure above the expected environmental background). In this way, it is intended to estimate the number of workers potentially exposed above background, rather than the number exposed at a level that might confer a risk of developing cancer. For this reason, there are inherently large proportions of workers who fall into the low category of exposure in our estimates. The benefit of a system that estimates all potential exposure, rather than precise estimates of people at risk, is largely a cost and effort benefit. Precise estimates would require regular effort.

### Table 1  Workplace exposure to known and suspected carcinogens, Canada, 2006

| IARC group | Agent | Data quality | n Exposed at work | % Of total workforce | Exposure levels available |
|------------|-------|--------------|-------------------|----------------------|--------------------------|
| Carcinogenic agents (IARC 1) | Solar radiation | Moderate | 1 476 000 | 8.8 | Yes |
| | Diesel engine exhaust | Low | 781 000 | 4.6 | No |
| | Silica (crystalline) | High | 382 000 | 2.3 | Yes |
| | Benzene | High | 374 000 | 2.2 | Yes |
| | Wood dust | High | 338 000 | 2.0 | Yes |
| | Asbestos | Low | 151 000 | 0.90 | No |
| | Formaldehyde | High | 151 000 | 0.90 | Yes |
| | Ultraviolet radiation (artificial sources) | Moderate | 141 000 | 0.83 | Yes |
| | Chromium (hexavalent) | High | 104 000 | 0.61 | Yes |
| | Ionising radiation | Moderate-high | 37 000–78 000 | 0.22–0.46 | Yes |
| | Cadmium | High | 31 000 | 0.18 | Yes |
| | Arsenic | Moderate | 25 000 | 0.15 | No |
| | Trichloroethylene | Moderate | 9800 | 0.06 | Yes |
| | Polychlorinated biphenyls | Low | 8200 | 0.05 | No |
| | Coal tar and coal tar pitches | Low | 7600 | 0.05 | No |
| | Beryllium | Low | 3900 | 0.02 | No |
| | 1,3-Butadiene | Low | 3900 | 0.02 | No |
| | Ethylene oxide | Moderate | 2400 | 0.01 | Yes |
| Probable carcinogenic agents (IARC 2A) | Shift work with potential for circadian disruption | High | 1 900 000 | 11.6 | Yes |
| | Tetrachloroethylene | High | 15 000 | 0.09 | Yes |
| | Acrylamide | Low | 9300 | 0.05 | No |
| | Epichlorohydrin | Low | 6600 | 0.04 | No |
| | Cresotes | Low | 4800 | 0.03 | No |
| Possible carcinogenic agents (IARC 2B) | Ethylbenzene | Low | 208 000 | 1.2 | No |
| | Styrene | High | 89 000 | 0.53 | Yes |
| | Bitumens | Low | 44 000 | 0.26 | No |
| | Dichloromethane | Moderate | 25 000 | 0.15 | Yes |
| | Toluene diisocyanates | Low | 24 000 | 0.14 | No |
| | Chloroform | Low | 15 800 | 0.09 | No |
| | Antimony trioxide | Low | 9700 | 0.06 | No |
| | Acetaldehyde | Low | 8600 | 0.05 | No |
| | Naphthalene | Low | 7700 | 0.05 | No |
| | Vanadium pentoxide | Low | 7100 | 0.04 | No |
| | Acrylonitrile | Low | 5900 | 0.04 | No |
| | Pentachlorophenol | Low | 4300 | 0.03 | No |
| | 1,4-Dioxane | Low | 3700 | 0.02 | No |
| | Refractory ceramic fibres | Low | 3200 | 0.02 | No |
| | 1,2-Dichloroethane | Low | 2000 | 0.01 | No |
| | Nitrobenzenene | Low | 500 | <0.01 | No |
| Mixed carcinogenic exposures | Polycyclic aromatic hydrocarbons | Low | 350 000 | 2.1 | No |
| Possible/probable carcinogenic agent (IARC 2B and 2A) | Lead | High | 277 000 | 1.6 | Yes |
| Possible/probable carcinogenic agent (IARC 2B and 2A) | Nickel | High | 117 000 | 0.69 | Yes |
| Possible/carcinogenic agent (IARC 2B and 1) | Antineoplastic agents | Moderate | 58 000 | 0.34 | Yes |
| Possible/probable carcinogenic agents (IARC 2B and 2A) | Cobalt | High | 33 000 | 0.19 | Yes |

IARC, International Agency for Research on Cancer.
surveys across Canada to identify individual workers at risk of exposure. Certainly, this would produce more accurate counts of workers exposed, but at a much higher cost. CAREX Canada’s estimates provide a more accessible and less costly way to identify workplaces with large workforces potentially exposed, and perhaps more importantly, to identify those who are at risk of high exposure (through the use of quantitative data).

The process of creating a CAREX system has inherent uncertainty. For substances that were initially reviewed by the EU CAREX project, we had a starting point to estimate proportions of workers exposed and apply them to Canadian Labour Force statistics. However, even in these cases, exposure proportions in the EU CAREX were more broadly classified than the systems used in Canada, and Canadian proportions required inference for particular industry and occupation combinations. For

Table 2 Exposure to known and suspected carcinogens by exposure level, Canada, 2006

| CAREX agent | High exposure (n) (%) | Moderate exposure (n) (%) | Low exposure (n) (%) | Total |
|-------------|-----------------------|--------------------------|---------------------|-------|
| Shift work  | 1 900 000 (100%)*    | –                        | –                   | 1 900 000 |
| Solar radiation | 896 000 (61%)           | 391 000 (26%)          | 190 000 (13%)       | 1 476 000 |
| Silica (crystalline) | 53 000 (14%)           | 147 000 (39%)          | 182 000 (48%)       | 382 000 |
| Benzene     | 1400 (<1%)             | 32 000 (9%)            | 341 000 (91%)       | 374 000 |
| Wood dust   | 93 000 (28%)            | 166 000 (49%)          | 79 000 (23%)        | 338 000 |
| Lead        | 60 000 (22%)            | 81 000 (29%)           | 136 000 (49%)       | 277 000 |
| Formaldehyde| 3700 (2%)               | 46 000 (30%)           | 102 000 (68%)       | 151 000 |
| Ultraviolet radiation (artificial sources) | 87 000 (62%)           | 34 000 (24%)           | 20 000 (14%)        | 141 000 |
| Nickel      | 8100 (7%)               | 12 000 (10%)           | 97 000 (83%)        | 117 000 |
| Chromium (hexavalent) compounds | 500 (<1%)              | 13 000 (12%)           | 90 000 (87%)        | 104 000 |
| Styrene     | 38 000 (43%)            | 28 000 (32%)           | 23 000 (26%)        | 89 000 |
| Ionising radiation† | <100                  | 10 000–18 000          | 26 000–60 000       | 36 000–78 000 |
| Antineoplastic agents | 5000 (9%)               | 40 000 (70%)           | 13 000 (21%)        | 58 000 |
| Cobalt      | 1800 (6%)               | 9500 (29%)             | 21 000 (65%)        | 33 000 |
| Cadmium     | 2200 (7%)               | 21 000 (66%)           | 8300 (27%)          | 31 000 |
| Dichloromethane (methylene chloride) | 3400 (13%)              | 8300 (33%)             | 14 000 (54%)        | 25 000 |
| Tetrachloroethylene | 700 (5%)               | 2200 (15%)             | 12 000 (80%)        | 15 000 |
| Trichloroethylene | 300 (3%)               | 5400 (55%)             | 4100 (42%)          | 9800 |

*Only those working regular night and rotating night shifts are reported as exposed.
†Results presented as a range due to the assumption that fewer workers are monitored for ionising radiation exposure than are actually exposed; see methods section for more details.

Table 3 Exposure to CAREX agents by broad industry group

| Industry subsector (two-digit NAICS code) | Total employed (n) | Number of exposures | Exposures per worker | Top three exposures |
|-----------------------------------------|-------------------|---------------------|----------------------|---------------------|
| 31-Manufacturing                        | 2 006 000         | 1 479 000           | 0.74                 | SHIFT, WOOD, BENZ   |
| 23-Construction                         | 1 069 000         | 1 188 000           | 1.11                 | SOL, SIL, WOOD      |
| 48-Transportation and warehousing       | 820 000           | 764 000             | 0.93                 | DEE, SOL, SHIFT     |
| 44-Retail trade                         | 1 917 000         | 553 000             | 0.29                 | SHIFT, PAH, BENZ    |
| 62-Health care and social assistance    | 1 716 000         | 468 000             | 0.27                 | SHIFT, ANTI, IRAD   |
| 11-Agriculture, forestry, fishing and hunting | 524 000           | 441 000             | 0.84                 | SOL, DEE, WOOD      |
| 91-Public administration                | 979 000           | 403 000             | 0.41                 | SOL, SHIFT, DEE     |
| 72-Accommodation and food services      | 1 127 000         | 400 000             | 0.35                 | SHIFT, PAH, SOL     |
| 81-Other services (except public administration) | 820 000           | 398 000             | 0.49                 | BENZ, PAH, ETHB     |
| 56-Administrative and support, waste management and remediation services | 723 000           | 269 000             | 0.37                 | SOL, SHIFT, DEE     |
| 21-Mining and oil and gas extraction   | 239 000           | 261 000             | 1.09                 | SHIFT, SOL, DEE     |
| 41-Wholesale trade                      | 739 000           | 175 000             | 0.24                 | DEE, SHIFT, SOL     |
| 71-Arts, entertainment and recreation  | 346 000           | 118 000             | 0.34                 | SOL, SHIFT, CHL     |
| 54-Professional, scientific and technical services | 1 122 000       | 86 000              | 0.08                 | SOL, SHIFT, SILI    |
| 51-Information and cultural industries  | 417 000           | 77 000              | 0.18                 | SHIFT, SOL, BENZ    |
| 61-Educational services                 | 1 151 000         | 73 000              | 0.06                 | SHIFT, SOL, FORM    |
| 22-Utilities                            | 133 000           | 55 000              | 0.41                 | SOL, SHIFT, IRAD    |
| 52-Finance and insurance                | 689 000           | 32 000              | 0.05                 | SHIFT, SOL, DEE     |
| 53-Real estate and rental and leasing   | 304 000           | 28 000              | 0.09                 | SOL, DEE, BENZ      |
| 55-Management of companies and enterprises | 21 000            | 3900                | 0.19                 | SHIFT, SOL, DEE     |

Total | 16 861 000 | 7 298 000 | 0.43 | SHIFT, SOL, DEE |
substances that were not estimated by the EU CAREX, our group would start from scratch, using peer-reviewed and grey literature, data from the CWED, and information from the National Occupational Exposure Survey from the USA. Coupled with expert assessment, these are the best available methods, though they have inherent uncertainty associated with them. For transparency, we applied a flag in the database for low confidence in all cases to document this occurrence.

Our estimates reflect instances of exposure that cannot be added, and so we are not able to calculate a total number of occupationally-exposed Canadians. This is a by-product of lack of individual-level data to account for situations where one worker may be exposed to a number of agents. In addition, we are not able to account for additive effects of either included agent exposures or other lifestyle effects (such as smoking) that could increase a worker’s risk of cancer. Other methods have been used to assess exposure to carcinogens on a national level, most recently in Australia, where telephone interviews of randomly-selected households in that country asked a series of questions about workplace exposure. This study was used to assess exposure overall due to the study design. In general, the proportion of Australians exposed to carcinogens was higher than in Canada, especially for solar UVR exposure (unsurprisingly given climate differences), diesel exhaust (17% exposed vs 4.6% in Canada) and silica (6% vs 2.3% in Canada). This is not unexpected given that the Australian study relied on self-reporting of tasks, which could be subject to bias. Alternatively (or in addition), Australia could truly have more prevalent exposure than Canada. The main limitation of our results centres on exposure data quality. To increase the sensitivity of our exposure level estimates, we applied conservative criteria when identifying a high exposure group. Therefore, if a group of workers is flagged as having high exposure, we are relatively confident that high exposure is occurring. If exposure data were not available for a particular job and industry combination, this group was automatically placed in the low exposure category for that substance. While this increases the robustness of our estimates in our use of quantitative exposure data, it means that there are likely to be groups of workers flagged in low exposure categories who actually could be at risk of high exposure. This is of particular importance for an industry such as construction. Here we know that high exposure is likely occurring (to agents such as wood dust, silica, diesel exhaust, etc) but since little monitoring data are included in the CWED (eg, none at all for diesel exhaust), we cannot confidently assign varying exposure levels for these workers. For diesel exhaust in particular, more studies have been done recently on exposure levels, and these could be used to enhance our estimates in the future.

Further to the point on data quality, the CWED data used to create the CAREX Canada estimates cover the time period of 1981–2004, with the bulk of the data being collected in the late 1980s and early 1990s. If exposure circumstances have changed substantially, our estimates could be improved by adding current exposure data to the CWED.

CAREX Canada’s estimates of the numbers of workers exposed to known or suspected carcinogens, and the simple system and tools used to enter and extract data, offer enhancements to previous CAREX projects. These data could be used to identify groups at risk of high exposure, assess the impact of changing regulations, identify gaps and research priorities, and account for occupational exposure on the burden of cancer.

We have shown that millions of Canadian workers are at risk of exposure to known and suspected carcinogens, some at high levels of exposure. We have also highlighted where issues of...
data quality impacted our ability to provide robust estimates of exposure, which could be used to guide future priority setting activities in Canada, and lead to better occupational cancer prevention at both Canadian and international levels.

Acknowledgements The authors wish to acknowledge Timo Kauppinen, both for his work in the development of the EU CAREX and for his encouragement of the CAREX Canada project. We would also like to acknowledge the input and hard work of the many past staff members and partners who contributed to our understanding of occupational exposure to carcinogens in Canada, especially Yat Chow, Barbara Lang, Anya Keefe and George Astrakianakis. Further thanks go to our Occupational Advisory Committee, which included Melissa Friesen, Judy Guernsey, France Labrèche, Jérôme Lavoué, John Oudyk and Jim Purdham. Finally, the authors wish to warmly acknowledge all contributors to the previous CAREX projects around the world.

Contributors PAD conceptualized the CAREX Canada project with CEP, and both designed the components of the exposure assessment (CEP completed many of them). CBG and ALH performed several of the exposure assessments. HWD participated in data gathering and creation and expansion of the CWED, as well as in critical review of the exposure assessments. All authors critically reviewed and revised the manuscript.

Funding Canadian Partnership Against Cancer.

Competing interests None.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement All data from the study are included in this publication.

Open Access This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/

REFERENCES
1 International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, 2013.
2 Siemiatycki J, Richardson L, Straif K, et al. Listing occupational carcinogens. Environ Health Perspect 2004;112:1447–59.
3 Setton E, Hystad P, Poplawski K, et al. Risk-based indicators of Canadians’ exposures to environmental carcinogens. Environ Health 2013;12:15.
4 Clapp RW, Jacobs MM, Loechler EL. Environmental and occupational causes of cancer: new evidence 2005–2007. Rev Environ Health 2008;23:1–37.
5 Kauppinen T, Toikkanen J, Pedersen D, et al. Occupational exposure to carcinogens in the European Union. Occup Environ Med 2000;57:10–18.

Peters CE, et al. Occup Environ Med 2015;72:64–71. doi:10.1136/oemed-2014-102286