Mortality Update of a Cohort of Canadian Petroleum Workers

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Objective: This study updates the mortality experience of over 25,000 workers in a large Canadian petroleum company through December 31, 2006. **Methods:** Standardized mortality ratios were generated for all-cause and specific cause mortality. **Results:** All cause and all cancer mortality were favorable compared with the general Canadian population. Cancers of previous interest were largely consistent with expectation. There is a continuing excess of mesothelioma, which is of similar magnitude as the previous update, although based on larger numbers. This excess is mostly attributable to men who died in their 50s and 60s and who worked in the refining sector. **Conclusion:** Most causes of death show mortality rates lower than the Canadian general population. Given the excess of mesothelioma observed, this study supports ongoing vigilance in asbestos exposure control programs, as refineries continue to remove asbestos from their facilities.

Keywords: Canada, Canadian, cause of death, mesothelioma, mortality, occupational cohort, petroleum workers

T he International Agency for Research on Cancer (IARC) has classified exposures in petroleum refining as probably carcinogenic to humans (Group 2A),[1] citing more than one significant elevation for both skin cancer and leukemia. Subsequently, excesses of both of these endpoints continue to be reported[2–5] in the refining and petrochemical industry, although not consistently. Other endpoints such as non-Hodgkin lymphoma (NHL) are also under investigation in these workers.[6,7] The complex exposure scenario in the petroleum industry includes carcinogens such as benzene, polycyclic aromatic hydrocarbons (PAHs), and asbestos. Thus, to assess potential risks from these and other outcomes, continued scrutiny of petroleum industry workers is warranted through occupational cohort mortality studies.

Several long-term health studies have been conducted to assess potential risks in a large Canadian petroleum cohort.[8–13] In general, these studies have shown an overall lower mortality for the cohort than that of the Canadian population, but not for every cause of death. The first cohort study[8] examined mortality of refinery workers employed between 1964 and 1973. The study found a two-fold risk of cancer mortality of the intestines (including rectum) and other digestive organs compared with nonrefinery workers.

The cohort was expanded to include all operating segments and updated mortality through 1983.[9] This update found statistically significant excesses for malignant melanoma [SMR = 1.87, 95% confidence interval (95% CI) = 1.07 to 3.04] and malignant mesothelioma (SMR = 5.65, 95% CI = 2.27 to 11.63). The melanoma excess was concentrated among upstream workers (SMR = 6.00, 95% CI = 2.19 to 13.06). Analyses of specific substances and hydrocarbon streams did not indicate an association with malignant melanoma. Mortality analysis of marketing/transportation workers showed nearly a two-fold but nonsignificant excess of multiple myeloma (SMR = 1.81, 95% CI = 0.73 to 3.73), which was also related to employment duration, latency, and starting employment before 1950. A subsequent study addressing this finding did not reveal an impact of occupational exposures to benzene or total hydrocarbons.[10]

The mortality experience of this cohort was again updated, extending the follow-up period through 1994.[11] The mesothelioma excess previously reported persisted in this cohort update (SMR = 8.68, 95% CI = 5.51 to 13.03). Most of the mesothelioma decedents were long-term employees with jobs that included presumed exposure to asbestos (mechanical and pipefitters). Deaths from multiple myeloma among marketing and distribution workers remained increased (SMR = 2.08, 95% CI = 0.95 to 3.95) within the 11-year update period, but there was no clear pattern by duration of employment or latency.

In 2003, the mortality experience of an inception cohort (those hired in 1964 to 1994) was analyzed.[12] Thus, unlike the previous studies, long-term survivors were excluded and the results were more applicable to modern work environments (previous studies included some workers employed before the 1920s). The size of this inception cohort was 25,292, and was established as the basis for all future updates. In addition, cancer morbidity was also assessed for the first time, using the Canadian Cancer Data Base (CCDB) to identify incident cancers diagnosed among employees between 1969 (the CCDB's start date) and 1994.

Analysis of the inception cohort found that gall bladder cancer mortality was increased among males. However, the increase was based on less than five deaths, none of which had common job assignments, and all had worked fewer than 10 years. Observed mesothelioma incidence in this inception cohort was reduced as expected (less than five cases) but was still greater than the number of mesothelioma cases expected from the general population (1.32). In addition to the overall cohort, exposure-specific analyses were conducted and showed associations between hydrogen sulfide (H_2S) and accidental deaths and petroleum coke and lung cancer. The petroleum coke/lung cancer association was further followed with additional smoking data as well as more specific exposure data, including asbestos exposure.[13] These results showed a stronger correlation between lung cancer and employment in the maintenance trades, rather than coke dust or asbestos, suggesting that multiple exposures experienced by workers in maintenance jobs were more predictive of lung cancer. It was anticipated that future updates of this inception cohort, with additional years of follow-up (viz, the present study), would be increasingly useful in monitoring the disease trends of more recent employees, especially for mesothelioma.

This present study extends monitoring of the mortality experience of employees who started work from 1964 through

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2006. Mortality patterns for specific causes of death (viz, lympho-hematopoietic (LH) cancers, lung cancer, mesothelioma, malignant melanoma, kidney cancer, gall bladder cancer and angiosarcoma of the liver) are the focus, to determine whether occupational factors influence these causes, and if so, the characterization and extent of the occupational factors' influence. Twelve additional years of mortality follow-up increase the statistical power to detect elevated health risks, if they are present, or likewise reveal the absence of such risks within the study population. Specific exposures were not captured in this update due to transitions in the exposure tracking software system. Benzene exposure in this population was previously studied in detail using a case–control approach with individual-based exposure assessment.[14] In the current study, the total work environment, which includes exposure to several hydrocarbon streams, H2S, benzene, polycyclic aromatic compounds, etc, was the focus. Any excesses found are assessed for occupational influences by duration of employment and latency.

METHODS

Research Design and Strategy

The design of this study is that of a retrospective cohort. The cohort is followed for mortality and rates of various diseases are compared with the rates expected in a comparable portion of the general Canadian population. Several health outcomes are of *a priori* interest based on the earlier studies' findings and/or on the epidemiology literature for petroleum workers. For statistical analyses, these causes of death are evaluated by gender, operating segment of the petroleum industry, and broad job classification. Any suggestive findings are further analyzed by typical occupational influences such as duration of employment and latency (eg, elapsed time between first hire and cancer death).

Data Sources and Definitions

Overall Cohort Source and Definition

The present cohort added 4087 employees, bringing the total cohort size to 29,379 workers. The cohort includes all employees from the previous investigation[12] as well as all employees hired between January 1, 1995, and December 31, 2006, who worked for at least a year.

Identification of the overall cohort was based upon the previous study's database and was supplemented by additional computerized work records from the company HR databases. The personnel and payroll systems are integral to the company's function, and are therefore a complete source for identification of company employees and their company-specific work assignments. The analysis was further restricted to employees with a minimum of 1-year employment.

Mortality Status Determination and Definition

The mortality experience of the cohort was updated through December 31, 2006; the last date for complete ascertainment when the study was initiated, using mortality tracing information from the Statistics Canada Mortality Database. Statistics Canada (SC) or provincial registrars obtained death certificates and the underlying cause of death. Underlying cause of death was determined by SC via the International Classification of Disease (ICD) classification scheme according to the revision in effect at the time of death. This assured comparability with the mortality rates used to compute the expected number of deaths for different cause of death categories. Records for employees were also matched to the U.S. National Death Index (NDI) to identify deaths that may have occurred among cohort members who may have transferred or immigrated to the United States.

For angiosarcoma of the liver and mesothelioma of the pleura and peritoneum, previous versions of the ICD scheme did not have a unique code. Thus, we requested that SC review all death certificates for mention of these causes. The specific ICD codes that may relate to both of these diagnoses have been published previously.[9] SC identified five mesotheliomas and less than five angiosarcomas via these manual searches.

Records not matched to either the SC mortality database nor the NDI, and not actively working or receiving benefits at the end of the study period ($n = 6171$) were potentially lost to follow-up (LTF). However, a further "alive tracing" by SC via Tax Summary files from 1984 to 2007 confirmed that only 3564 were LTF as of 2006. Privacy legislation in Canada prevented the identification of these individuals; hence, 3564 of the 6171 workers were selected using a stratified random sampling approach (see statistical analysis section).

Demographic and Work History Sources and Definition

All demographic data (eg, age, gender) for employees were obtained from the company's Human Resource payroll and personnel computerized systems. This information is continuously validated by the company. An operating segment was defined as a part of the industry where different operations are present (eg, "refining" produces products from crude oil, "upstream" consists of the exploration, drilling and production of crude oil or gas, etc). Operating segments were documented well in each employee's work history, and consisted of refinery, agricultural chemicals, petrochemical, marketing, transportation, marine, exploration/drilling/production (upstream), pipeline, coal and minerals, office, and fabricated building products subsidiary. This scheme was developed by three experienced company industrial hygienists. Employees were classified as "ever employed" in an operating segment, such that an employee could be defined in more than one operating segment. In addition, the "Exposure Group" (EG) field, which was linked to the work history (98% linked) from the company's Exposure Tracking and Health Information System (ETHIS),[12] was used in analyses. The EG field (hence: job group) describes the jobs among employees who perform similar work tasks and contains the following entries: operations, maintenance, transportation, lab/research, as well as other smaller groups. The job group field was also used to identify employees who were nonexposed or minimally exposed to company operations. For all nonexposed job groups, employees were only classified as such if they never worked in an exposed job group. For exposed job groups, employees were classified as "ever employed"; thus, an employee could be represented in more than one exposed job group, although overlap is minimal.

Data Quality

Data quality assurance was built into designated phases of the project. Company staff performed quality checks on fields abstracted from the payroll and personnel systems. These included out-of-range checks as well as consistency checks between fields. All dates were tested for completeness and logical progressions. Frequency counts were obtained before and after data were received from SC to identify any transcription errors. Within SC, procedures for matching potential deaths and cancer cases to records of cohort members are well developed, and use the Generalized Record Linkage System (GRLS).

Statistical Analysis

Eligible employees were entered into follow-up for mortality 1 year after their date of hire within the cohort entry requirements discussed above. Person-years at risk were accumulated by age, gender, and within quinquennia until the earlier of date of death or the end of study (December 31, 2006). Persons of unknown vital status (LTF) were assumed to be alive until their date last observed (DLO), which was usually date last employed. As the 3564 LTFs were selected from the 6171 original LTF (before additional SC "alive tracing"), we ensured that these workers had the same

distribution for DLO as the original 6171 LTF employees by randomly selecting the 3564 LTF within 5-year DLO strata for the 6171 workers. We also performed sensitivity analyses on different LTF strategies to examine the impact of these assumptions.

Expected numbers of cancer cases and deaths were computed using a modified life table approach with the software package OCMAP-Plus, version 3.10 (University of Pittsburgh, Pittsburgh, PA). Expected deaths were calculated by multiplying person-years by mortality rates for the general Canadian population according to age, sex, and calendar time. Mortality rates were obtained from SC databases. Observed deaths were divided by expected deaths to generate standardized mortality ratios (SMRs). Males and females in each of these employment categories were analyzed separately. SMRs and 95% CIs were computed for several causes of death and diagnostic codes. To limit presentation of less meaningful results, SMRs were computed when there are at least five observed outcomes. Although tabulated data for operating segments and job groups represent "ever worked" and are not mutually exclusive, the observed numbers of death for any cause were tabulated only if there were zero deaths or when they reached five or more deaths. This is consistent with disclosure controls for mortality data obtained from the Canadian Vital Statistics Death Database. These disclosure rules were also applied to other tabulated data in this report.

RESULTS

A total of 29,379 workers contributed 702,906 person-years at risk between 1964 and 2006, for an average of about 24 years of follow-up per employee. The distribution of persons by gender, vital status, and other attributes is displayed in Table 1. The mean age of the cohort at the beginning and end of follow-up was 27 and 54 years, respectively. At the end of follow-up, 75% of the cohort was at least age 47, 50% of the cohort was age 54, 25% of the cohort was at least age 60, and 5% of the cohort was at least age 71. Compared with the initial publication of this inception cohort, this population consists of 4087 (16%) additional workers and 309,094 (78%) additional person-years, while average follow-up time increased from 17 to 27 years.

Mortality

A total of 1669 observed deaths occurred compared with 2418.5 expected deaths, for an all-cause SMR of 0.69 (95% CI = 0.66 to 0.72) (Table 2). All-cause SMRs were similar among men, SMR of 0.70 (95% CI = 0.66 to 0.74) and women, SMR of 0.66 (95% CI = 0.59 to 0.74). For the total cohort, nearly all major categories of death were significantly reduced compared with national background rates (Table 2). The only significant excess was for mesothelioma, where nine deaths were observed, based on 10th revision coding, compared with 2.8 expected for a significantly raised SMR of 3.27 (95% CI = 1.50 to 6.21).

The 2003 update of this cohort reported a statistical excess of gall bladder cancer based on less than five deaths.[12] For this update, no additional gall bladder cancer deaths were found, while there are now a total of 4.9 expected cases (Table 2).

Findings for other *a priori* causes of death were generally unremarkable for the total cohort (Table 2). Cancers of the colon (large intestine), lung (bronchus and lung), and kidney showed lower observed versus expected numbers of death. Melanoma and leukemias also showed reduced SMRs.

There was a moderate excess of amyotrophic lateral sclerosis (ALS) based on 15 observed deaths and 8.8 expected deaths for men and women combined, though it was not statistically significant (SMR = 1.70, 95% CI = 0.95 to 2.80) (Table 2).

For aortic aneurysm (AA), and the more inclusive category of "Diseases of the arteries, arterioles and capillaries" (DAAC), the SMRs for men versus women were in the opposite direction. Women showed nonsignificant excesses of both diseases (SMR for DAAC = 1.89, 95% CI = 0.87 to 3.59; SMR for AA = 2.48, 95% CI = 0.80 to 5.78). However, men showed deficits for both diseases (SMR for DAAC = 0.44, 95% CI = 0.22 to 0.80; SMR for AA = 0.62, 95% CI = 0.28 to 1.18). There were no other notable differences in male versus female mortality for the entire cohort.

Mortality by Operating Segment

The excess of mesothelioma mortality was largely due to an excess in refinery workers (six observed, SMR = 9.93, 95% CI = 3.64 to 21.60) (Table 3). Most *a priori* cancers (viz. melanoma, leukemia, colon cancer) had observed numbers of death consistent with expectation in refinery workers. The SMR for cancers of unknown sites was 1.60 based on 11 cases but was not statistically significant.

There were no statistically significant increased SMRs in petrochemical workers (Table 3). When refinery and petrochemical workers were combined, the findings noted above in refinery workers did not increase in magnitude. Of note, lung cancer showed 40 versus 59 deaths in these two segments, which together showed slight lung cancer excesses within normal statistical variation as previously reported.[13]

There were no statistically significant excess mortality findings in upstream workers (Table 3), including for malignant melanoma, which was elevated for the larger older cohort. A previous observation of an increased incidence of motor vehicle accidents was found to be similar to expected numbers in this current update.

Transportation workers showed a nonsignificant elevation due to ALS, n = 5, SMR = 2.15, 95% CI = 0.70 to 5.03 (Table 3).

Mortality by Job Group

Job groups with sufficient numbers included maintenance, operations, and distribution, and are summarized in Table 4.

TABLE 1. Characteristics of Canadian Petroleum Cohort (1964–2006)

Characteristics	Males	Females	Total Cohort
Total	19,942	9,437	29,379
Alive	16,104	8,042	24,146
Deceased	1,350	319	1,669
Lost to follow-up	2,488	1,076	3,564
Total person-years	480,787	222,119	702,906
Date first employed (average)	May 04, 1979	June 20, 1980	September 13, 1979
Date of termination (average)	January 9, 1988	December 27, 1986	September 02, 1987
Average years worked	9.8	7.3	8.9
Average age at entry	27.5	26.2	27.1
Average age at last observation	54.4	52.4	53.8
Percent < 5 years worked	46.2	44.2	45.5

TABLE 2. Mortality Results for Canadian Petroleum Cohort (1964–2006)

Cause of Death	Overall Cohort			MEN ONLY			WOMEN ONLY		
	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)
All causes	1,669	2,418.5	0.69 (0.66–0.72)†	1,350	1,937.4	0.70 (0.66–0.74)†	319	481.0	0.66 (0.59–0.74)†
Infective and parasitic disease (Dx)	27	59.4	0.46 (0.30–0.66)†	14	52.3	—	—	7.0	—
Acquired immune deficiency syndrome	14	33.5	0.42 (0.23–0.70)†	—	32.3	0.43 (0.24–0.73)†	0	1.2	—
Malignant neoplasms (MN)	633	808.0	0.78 (0.72–0.85)†	466	592.8	0.79 (0.72–0.86)†	167	215.2	0.78 (0.66–0.90)†
MN buccal cavity and pharynx	10	20.3	0.49 (0.24–0.91)‡	10	18.0	0.56 (0.27–1.02)	0	2.3	—
MN esophagus	17	22.0	0.77 (0.45–1.24)	—	20.3	—	—	1.8	—
MN stomach	24	28.0	0.86 (0.55–1.28)	—	23.1	—	—	4.8	—
MN large intestine except rectum	55	71.3	0.77 (0.58–1.00)	46	54.4	0.85 (0.62–1.13)	9	16.9	0.53 (0.24–1.01)
MN rectum and rectosigmoid junction	19	20.6	0.92 (0.56–1.44)	—	16.7	—	—	3.8	—
MN liver	6	13.7	0.44 (0.16–0.95)‡	6	11.8	0.51 (0.19–1.10)	0	1.9	—
MN gallbladder	x	4.9	—	x	3.2	—	0	1.7	—
MN pancreas	33	39.1	0.84 (0.58–1.19)	25	30.5	0.82 (0.53–1.21)	8	8.6	0.93 (0.40–1.82)
MN nose/sinuses	x	1.1	—	x	0.9	—	0	0.2	—
MN bronchus and lung	168	233.9	0.72 (0.61–0.84)†	130	185.8	0.70 (0.58–0.83)†	38	48.1	0.79 (0.56–1.09)
MN bone	0	2.4	—	0	2.0	—	0	0.5	—
Malignant melanoma	9	15.5	0.58 (0.27–1.10)	—	12.2	—	—	3.3	—
MN of connective and other soft tissue	5	5.9	0.85 (0.28–1.99)	—	4.2	—	—	1.6	—
Mesothelioma	9	2.8	3.27 (1.50–6.21)†	—	2.5	—	—	0.2	—
MN breast	43	50.9	0.85 (0.61–1.14)	0	0.7	—	43	50.2	0.86 (0.62–1.16)
MN cervix uteri	x	6.2	—	0	0.0	—	x	6.2	—
MN corpus uteri	x	2.1	—	0	0.0	—	x	2.1	—
MN ovary/Fallopian tube/Broad ligament	14	12.8	1.10 (0.60–1.84)	0	0.0	—	14	12.8	1.10 (0.60–1.84)
MN prostate	24	26.9	0.89 (0.57–1.33)	24	26.9	0.89 (0.57–1.33)	0	0.0	—
MN testis	x	2.3	—	x	2.3	—	0	0.0	—
MN kidney	15	20.9	0.72 (0.40–1.18)	—	17.6	—	—	3.3	—
MN bladder	14	13.3	1.05 (0.58–1.77)	—	11.7	—	—	1.6	—
Nervous system malignant, benign, and unspecified	36	38.8	0.93 (0.65–1.29)	29	30.4	0.96 (0.64–1.37)	7	8.4	0.83 (0.34–1.72)
All brain tumors	33	36.7	0.90 (0.62–1.26)	27	28.9	0.94 (0.62–1.36)	6	7.8	0.77 (0.28–1.68)
MN - Brain	31	32.6	0.95 (0.65–1.35)	26	25.8	1.01 (0.66–1.48)	5	6.9	0.73 (0.24–1.70)
MN CNS tumors (excluding brain)	x	0.8	—	x	0.6	—	x	0.2	—
MN site unknown	28	36.7	0.76 (0.51–1.10)	17	27.4	0.62 (0.36–0.99)‡	11	9.3	1.18 (0.59–2.11)
Hodgkin disease	6	4.7	1.26 (0.46–2.75)	—	3.8	—	—	0.9	—
Non-Hodgkin lymphoma	27	31.7	0.85 (0.56–1.24)	20	25.0	0.80 (0.49–1.23)	7	6.6	1.06 (0.42–2.18)
Diffuse non-Hodgkin lymphoma	15	16.5	0.91 (0.51–1.50)	—	13.1	—	—	3.4	—
Follicular non-Hodgkin lymphoma	18	15.6	1.15 (0.68–1.82)	13	12.4	1.05 (0.56–1.80)	5	3.2	1.55 (0.50–3.62)
Leukemias	23	28.5	0.81 (0.51–1.21)	18	22.3	0.81 (0.48–1.27)	5	6.2	0.81 (0.26–1.88)
Acute nonlymphocytic leukemia	10	13.7	0.73 (0.35–1.35)	—	10.3	—	—	3.4	—
Acute myeloid leukemia	8	9.4	0.85 (0.37–1.67)	x	7.1	—	0	2.4	—
Chronic myeloid leukemia	x	3.7	—	x	2.9	—	x	0.8	—
Acute lymphoid leukemia	x	2.5	—	—	1.9	—	—	0.6	—
Chronic lymphoid leukemia	6	4.3	1.40 (0.51–3.04)	x	3.7	—	0	0.6	—
Other leukemia	x	4.6	—	—	3.7	—	x	0.9	—
Multiple myeloma and immunoproliferative Dx	12	11.9	1.01 (0.52–1.76)	x	9.3	—	—	2.6	—
Multiple myeloma	9	11.8	0.76 (0.35–1.45)	x	9.2	—	0	2.6	—
Myelodysplastic syndrome	x	1.7	—	0	1.4	—	0	0.3	—
Chronic myeloproliferative disease	x	1.5	—	x	1.2	—	x	0.3	—
Benign neoplasms	0	2.1	—	x	1.4	—	0	0.7	—
Disease of blood and blood-forming organs	x	6.3	—	x	4.5	—	0	1.7	—
Aplastic anemia	x	1.1	—	x	0.8	—	0	0.3	—

TABLE 2. (Continued)

	Overall Cohort			MEN ONLY			WOMEN ONLY		
Cause of Death	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)
Endocrine/Nutritional/Metabolic disease	40	76.6	0.52 (0.37–0.71)†	34	60.9	0.56 (0.39–0.78)†	6	15.7	0.38 (0.14–0.83)‡
Diabetes mellitus	33	57.5	0.57 (0.40–0.81)†	—	46.0	—	—	11.5	—
Amyotrophic lateral sclerosis	15	8.8	1.70 (0.95–2.80)	—	6.9	—	—	1.9	—
Circulatory disease	426	637.9	0.67 (0.61–0.73)†	360	541.2	0.67 (0.60–0.74)†	66	96.6	0.68 (0.53–0.87)†
Cerebrovascular disease	56	88.2	0.64 (0.48–0.83)†	42	65.0	0.65 (0.47–0.87)†	14	23.2	0.60 (0.33–1.01)
Acute myocardial infarction	137	241.3	0.57 (0.48–0.67)†	122	214.9	0.57 (0.47–0.68)†	15	26.4	0.57 (0.32–0.94)‡
Diseases of arteries, arterioles, and capillaries	20	29.5	0.68 (0.41–1.05)	11	24.8	0.44 (0.22–0.80)†	9	4.8	1.89 (0.87–3.59)
Aortic aneurysm	14	16.5	0.85 (0.46–1.42)	9	14.5	0.62 (0.28–1.18)	5	2.0	2.48 (0.80–5.78)
Respiratory disease	65	107.8	0.60 (0.47–0.77)†	55	83.8	0.66 (0.49–0.85)†	10	23.9	0.42 (0.20–0.77)†
Chronic obstructive pulmonary disease	24	40.0	0.60 (0.39–0.89)†	19	31.3	0.61 (0.37–0.95)‡	5	8.6	0.58 (0.19–1.35)
Digestive disease	68	108.0	0.63 (0.49–0.80)†	55	88.2	0.62 (0.47–0.81)†	13	19.8	0.66 (0.35–1.12)
Cirrhosis of liver	39	60.5	0.65 (0.46–0.88)†	33	51.6	0.64 (0.44–0.90)†	6	8.9	0.67 (0.25–1.47)
Diseases of pancreas	x	5.3	—	x	4.5	—	0	0.9	—
Genitourinary disease	14	23.5	0.60 (0.33–1.00)	—	17.8	—	—	5.7	—
Kidney diseases	12	20.4	0.59 (0.31–1.03)	—	15.7	—	—	4.7	—
Accidents/Poisonings/Violence	259	421.1	0.62 (0.54–0.70)†	238	366.7	0.65 (0.57–0.74)†	21	54.4	0.39 (0.24–0.59)†
Motor vehicle traffic accidents	85	109.7	0.78 (0.62–0.96)‡	79	93.9	0.84 (0.67–1.05)	6	15.8	0.38 (0.14–0.83)†
Motor vehicle nontraffic accidents	x	4.2	—	x	3.9	—	0	0.2	—
Water transport accidents	6	8.1	0.74 (0.27–1.60)	6	7.9	0.76 (0.28–1.66)	0	0.3	—
Air and space transport accidents	7	5.8	1.21 (0.49–2.49)	—	5.5	—	0	0.3	—
All other accidents	61	111.8	0.55 (0.42–0.70)†	—	98.8	—	—	13.0	—
Suicide	82	141.9	0.58 (0.46–0.72)†	72	124.4	0.58 (0.45–0.73)†	10	17.5	0.57 (0.27–1.05)

x Observations in the 1–4 observed range are not reported in accordance with disclosure rules of Statistics Canada.
– Observed numbers are not reported if subtraction could disclose an observation in the 1–4 range, in accordance with disclosure rules of Statistics Canada.
SMR (95% CI), standardized mortality ratio (95% confidence interval).
*Expected deaths based on Canadian general population mortality rates.
†Statistically significant at P < 0.01.
‡Statistically significant at P < 0.05.

TABLE 3. Mortality Results by Operating Segment of a Canadian Petroleum Cohort (1964–2006), Men and Women Combined

	Refinery			Petrochemical			Upstream			All Transportation		
Cause of Death	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)
All Causes	341	477.4	0.71 (0.64–0.79)†	83	148.9	0.56 (0.44–0.69)†	310	518.0	0.60 (0.53–0.67)†	489	619.4	0.79 (0.72–0.86)†
Infective and parasitic disease (Dx)	x	13.6	—	0	4.4	—	x	15.8	—	7	13.3	0.53 (0.21–1.09)
Acquired immune deficiency syndrome	x	8.4	—	0	2.7	—	x	10.0	—	x	6.9	—
Malignant neoplasms (MN)	131	150.0	0.87 (0.73–1.04)	34	48.7	0.70 (0.48–0.98)‡	112	165.6	0.68 (0.56–0.81)†	191	210.6	0.91 (0.78–1.04)
MN buccal cavity and pharynx	x	4.3	—	0	1.4	—	x	4.3	—	x	5.7	—
MN esophagus	6	4.8	1.25 (0.46–2.72)	0	1.5	—	x	4.7	—	6	6.3	0.95 (0.35–2.08)
MN stomach	0	5.6	—	x	1.7	—	6	5.8	1.04 (0.38–2.27)	10	7.6	1.31 (0.63–2.41)
MN large intestine except rectum	16	13.4	1.19 (0.68–1.94)	x	4.3	—	11	14.4	0.76 (0.38–1.36)	13	19.0	0.69 (0.37–1.17)

TABLE 3. (Continued)

Cause of Death	Refinery			Petrochemical			Upstream			All Transportation		
	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)
MN rectum and rectosigmoid junction	x	4.1	—	x	1.3	—	x	4.2	—	7	5.6	1.25 (0.50–2.58)
MN liver	x	2.9	—	0	0.9	—	x	3.0	—	x	3.7	—
MN gallbladder	0	0.8	—	0	0.3	—	x	1.0	—	x	1.2	—
MN pancreas	7	7.6	0.93 (0.37–1.91)	0	2.4	—	9	8.0	1.13 (0.52–2.14)	12	10.5	1.14 (0.59–2.00)
MN nose/sinuses	0	0.2	—	x	0.1	—	x	0.3	—	x	0.3	—
MN bronchus and lung	29	44.9	0.65 (0.43–0.93)‡	11	14.4	0.76 (0.38–1.37)	22	46.9	0.47 (0.29–0.71)†	62	64.7	0.96 (0.73–1.23)
MN bone	0	0.5	—	0	0.2	—	0	0.6	—	0	0.6	—
Malignant melanoma	x	3.2	—	0	1.0	—	x	3.5	—	0	3.8	—
MN of connective and other soft tissue	x	1.1	—	0	0.4	—	x	1.4	—	x	1.4	—
Mesothelioma	6	0.6	9.93 (3.64–21.60)†	0	0.2	—	x	0.6	—	x	0.8	—
MN breast	7	4.1	1.71 (0.69–3.52)	x	2.1	—	5	9.8	0.51 (0.17–1.20)	6	8.2	0.73 (0.27–1.60)
MN cervix uteri	x	0.5	—	0	0.2	—	0	1.3	—	x	1.0	—
MN corpus uteri	0	0.1	—	0	0.1	—	0	0.4	—	0	0.3	—
MN ovary/fallopian tube/broad ligament	0	1.0	—	0	0.5	—	x	2.4	—	x	2.0	—
MN prostate	6	5.3	1.12 (0.41–2.45)	0	1.5	—	5	4.9	1.02 (0.33–2.38)	10	8.5	1.18 (0.57–2.18)
MN testis	x	0.6	—	0	0.2	—	0	0.6	—	x	0.5	—
MN kidney	x	4.3	—	0	1.4	—	x	4.4	—	8	5.7	1.40 (0.61–2.76)
MN bladder	x	2.6	—	0	0.8	—	x	2.6	—	x	3.8	—
Nervous system malignant, benign, and unspecified	5	7.9	0.63 (0.21–1.47)	x	2.5	—	12	8.8	1.37 (0.71–2.39)	8	9.6	0.83 (0.36–1.64)
All brain tumors	5	7.6	0.66 (0.22–1.55)	x	2.4	—	11	8.3	1.32 (0.66–2.36)	7	9.1	0.77 (0.31–1.58)
MN - Brain	5	6.7	0.74 (0.24–1.73)	x	2.2	—	10	7.4	1.35 (0.65–2.48)	7	8.1	0.86 (0.35–1.78)
MN CNS tumors (excluding brain)	0	0.2	—	0	0.0	—	x	0.2	—	0	0.2	—
MN site unknown	11	6.9	1.60 (0.80–2.87)	x	2.2	—	x	7.6	—	x	9.6	—
Hodgkin disease	0	1.0	—	0	0.3	—	x	1.1	—	x	1.1	—
Non-Hodgkin lymphoma	6	6.4	0.94 (0.35–2.06)	x	2.0	—	5	6.9	0.73 (0.24–1.70)	8	8.2	0.98 (0.42–1.92)
Diffuse non-Hodgkin lymphoma	x	3.3	—	x	1.0	—	x	3.5	—	x	4.2	—
Follicular non-Hodgkin lymphoma	x	3.1	—	x	1.0	—	x	3.3	—	x	4.0	—
Leukemias	x	5.6	—	x	1.7	—	5	6.1	0.83 (0.27–1.92)	8	7.3	1.10 (0.48–2.17)
Acute nonlymphocytic leukemia	x	2.6	—	x	0.8	—	x	2.9	—	x	3.4	—
Acute myeloid leukemia	x	1.8	—	0	0.6	—	x	2.0	—	x	2.4	—
Chronic myeloid leukemia	0	0.7	—	0	0.2	—	0	0.8	—	x	0.9	—
Acute lymphoid leukemia	x	0.5	—	x	0.2	—	0	0.6	—	0	0.6	—
Chronic lymphoid leukemia	0	0.8	—	x	0.3	—	x	0.8	—	x	1.2	—
Other leukemia	0	0.9	—	0	0.3	—	x	1.0	—	x	1.2	—
Multiple myeloma and immunoproliferative Dx	0	2.3	—	x	0.7	—	x	2.4	—	x	3.2	—

TABLE 3. (Continued)

Cause of Death	Refinery Observed	Refinery Expected*	Refinery SMR (95% CI)	Petrochemical Observed	Petrochemical Expected*	Petrochemical SMR (95% CI)	Upstream Observed	Upstream Expected*	Upstream SMR (95% CI)	All Transportation Observed	All Transportation Expected*	All Transportation SMR (95% CI)
Multiple myeloma	0	2.2	—	x	0.7	—	x	2.4	—	x	3.2	—
Myelodysplastic syndrome	0	0.3	—	0	0.1	—	x	0.3	—	0	0.5	—
Chronic myeloproliferative disease	0	0.3	—	0	0.1	—	x	0.3	—	0	0.4	—
Benign neoplasms	0	0.4	—	0	0.1	—	x	0.4	—	0	0.5	—
Dx of blood and blood-forming organs	0	1.2	—	x	0.4	—	x	1.3	—	0	1.5	—
Aplastic anemia	0	0.2	—	0	0.1	—	x	0.2	—	0	0.3	—
Endocrine/Nutritional/Metabolic Dx	7	14.9	0.47 (0.19–0.97)‡	x	4.7	—	10	16.2	0.62 (0.30–1.14)	13	20.0	0.65 (0.35–1.11)
Diabetes mellitus	6	11.1	0.54 (0.20–1.17)	x	3.5	—	8	11.9	0.67 (0.29–1.32)	13	15.3	0.85 (0.45–1.45)
Amyotrophic lateral sclerosis	x	1.7	—	x	0.6	—	x	1.9	—	5	2.3	2.15 (0.70–5.03)
Circulatory disease	92	125.8	0.73 (0.59–0.90)†	19	38.1	0.50 (0.30–0.78)†	55	128.2	0.43 (0.32–0.56)†	143	175.5	0.82 (0.69–0.96)‡
Cerebrovascular disease	11	15.6	0.71 (0.35–1.26)	x	4.8	—	6	17.3	0.35 (0.13–0.75)†	14	22.6	0.62 (0.34–1.04)
Acute myocardial infarction	25	49.4	0.51 (0.33–0.75)†	5	14.8	0.34 (0.11–0.79)†	18	48.1	0.38 (0.22–0.59)†	61	68.6	0.89 (0.68–1.14)
Diseases of arteries, arterioles, and capillaries	5	5.6	0.90 (0.29–2.10)	x	1.7	—	x	5.7	—	x	8.2	—
Aortic aneurysm	x	3.2	—	x	1.0	—	x	3.2	—	x	4.7	—
Respiratory disease	13	19.1	0.68 (0.36–1.17)	x	5.7	—	13	20.7	0.63 (0.34–1.08)	18	28.8	0.63 (0.37–0.99)‡
Chronic obstructive pulmonary Dx	x	6.7	—	0	2.0	—	5	7.2	0.70 (0.23–1.62)	6	11.1	0.54 (0.20–1.17)
Digestive disease	15	21.8	0.69 (0.39–1.13)	x	6.8	—	15	23.0	0.65 (0.37–1.08)	18	28.5	0.63 (0.37–0.99)‡
Cirrhosis of liver	10	12.8	0.78 (0.37–1.43)	x	4.0	—	10	13.1	0.76 (0.37–1.41)	11	16.3	0.67 (0.34–1.21)
Diseases of pancreas	0	1.1	—	0	0.3	—	x	1.2	—	x	1.4	—
Genitourinary disease	x	4.2	—	0	1.3	—	x	4.6	—	7	6.1	1.14 (0.46–2.35)
Kidney diseases	x	3.7	—	0	1.1	—	x	4.0	—	6	5.4	1.12 (0.41–2.44)
Accidents/Poisonings/Violence	60	93.9	0.64 (0.49–0.82)†	13	28.3	0.46 (0.25–0.79)†	74	104.6	0.71 (0.56–0.89)†	60	94.2	0.64 (0.49–0.82)†
Motor vehicle traffic accidents	19	24.0	0.79 (0.48–1.23)	x	6.9	—	27	26.3	1.03 (0.68–1.50)	21	23.8	0.88 (0.55–1.35)
Motor vehicle nontraffic accidents	0	1.0	—	x	0.3	—	x	1.1	—	0	0.9	—
Water transport accidents	x	1.9	—	0	0.5	—	x	1.9	—	0	2.0	—
Air and space transport accidents	x	1.4	—	0	0.4	—	x	1.4	—	x	1.4	—
All other accidents	16	24.9	0.64 (0.37–1.04)	x	7.5	—	18	27.3	0.66 (0.39–1.04)	14	26.2	0.54 (0.29–0.90)‡
Suicide	19	32.2	0.59 (0.36–0.92)‡	x	10.0	—	16	36.7	0.44 (0.25–0.71)†	19	31.3	0.61 (0.37–0.95)‡

x Observations in the 1–4 observed range are not reported in accordance with disclosure rules of Statistics Canada.
SMR (95% CI), standardized mortality ratio (95% confidence interval).
*Expected deaths based on Canadian general population mortality rates.
†Statistically significant at $P < 0.01$.
‡Statistically significant at $P < 0.05$.

TABLE 4. Mortality Results by Job Group of a Canadian Petroleum Cohort (1964–2006), Men and Women Combined

Cause of Death	Maintenance			Operations			Distribution			Miscellaneous Exposure		
	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)
All causes	217	283.0	0.77 (0.67–0.88)†	391	540.1	0.72 (0.65–0.80)†	127	126.7	1.00 (0.84–1.19)	147	187.1	0.79 (0.66–0.92)†
Infective and parasitic disease (Dx)	x	7.8	—	6	16.6	0.36 (0.13–0.79)†	0	2.4	—	0	4.2	—
Acquired immune deficiency syndrome	0	4.9	—	x	10.9	—	0	1.2	—	0	2.4	—
Malignant neoplasms (MN)	95	86.5	1.10 (0.89–1.34)	127	159.0	0.80 (0.67–0.95)‡	41	42.7	0.96 (0.69–1.30)	55	58.8	0.94 (0.71–1.22)
MN buccal cavity and pharynx	x	2.7	—	x	4.9	—	x	1.3	—	0	1.7	—
MN esophagus	x	2.9	—	x	5.4	—	x	1.4	—	x	1.9	—
MN stomach	0	3.4	—	7	6.2	1.14 (0.46–2.34)	x	1.7	—	x	2.3	—
MN large intestine except rectum	11	7.9	1.40 (0.70–2.50)	15	14.4	1.04 (0.58–1.72)	x	4.0	—	6	5.4	1.11 (0.41–2.43)
MN rectum and rectosigmoid junction	x	2.4	—	x	4.5	—	x	1.2	—	0	1.6	—
MN liver	x	1.7	—	x	3.3	—	0	0.8	—	0	1.1	—
MN gallbladder	0	0.5	—	x	0.8	—	0	0.2	—	x	0.3	—
MN pancreas	6	4.4	1.36 (0.50–2.95)	7	8.1	0.86 (0.35–1.78)	x	2.2	—	x	3.0	—
MN nose/sinuses	0	0.1	—	0	0.3	—	0	0.1	—	x	0.1	—
MN bronchus and lung	24	27.1	0.89 (0.57–1.32)	27	48.5	0.56 (0.37–0.81)†	14	14.1	0.99 (0.54–1.66)	24	18.7	1.28 (0.82–1.91)
MN bone	0	0.3	—	0	0.6	—	0	0.1	—	0	0.2	—
Malignant melanoma	x	1.8	—	x	3.6	—	0	0.8	—	0	1.1	—
MN of connective and other soft tissue	x	0.6	—	x	1.3	—	0	0.3	—	0	0.4	—
Mesothelioma	x	0.4	—	x	0.7	—	0	0.2	—	0	0.2	—
MN breast	0	0.2	—	0	0.8	—	0	0.1	—	0	0.4	—
MN cervix uteri	0	0.0	—	0	0.1	—	0	0.0	—	0	0.1	—
MN corpus uteri	0	0.0	—	0	0.0	—	0	0.0	—	0	0.0	—
MN Ovary/Fallopian tube/Broad ligament	0	0.0	—	0	0.1	—	0	0.0	—	0	0.1	—
MN prostate	x	3.6	—	9	6.2	1.46 (0.67–2.77)	x	1.9	—	x	3.0	—
MN testis	0	0.3	—	x	0.7	—	0	0.1	—	0	0.2	—
MN kidney	x	2.6	—	x	4.8	—	x	1.2	—	x	1.7	—
MN bladder	5	1.7	3.01 (0.98–7.03)	x	2.9	—	x	0.8	—	0	1.2	—
Nervous system malignant, benign, and unspecified	x	4.5	—	11	8.9	1.24 (0.62–2.22)	x	2.0	—	x	2.7	—
All brain tumors	x	4.3	—	11	8.5	1.30 (0.65–2.33)	x	1.9	—	x	2.6	—
MN - brain	x	3.9	—	10	7.5	1.33 (0.64–2.44)	x	1.7	—	x	2.3	—
MN CNS tumors (excluding brain)	0	0.1	—	0	0.2	—	0	0.0	—	0	0.1	—
MN site unknown	7	4.0	1.77 (0.71–3.63)	6	7.3	0.82 (0.30–1.79)	0	2.0	—	x	2.7	—
Hodgkin disease	0	0.6	—	x	1.2	—	0	0.2	—	0	0.3	—
Non-Hodgkin lymphoma	x	3.7	—	x	7.0	—	x	1.7	—	x	2.3	—
Diffuse Non-Hodgkin lymphoma	x	2.0	—	x	3.6	—	0	0.9	—	x	1.2	—
Follicular non-Hodgkin lymphoma	x	1.8	—	x	3.4	—	0	0.9	—	x	1.2	—

TABLE 4. (Continued)

Cause of Death	Maintenance			Operations			Distribution			Miscellaneous Exposure		
	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)
Leukemias	x	3.3	—	x	6.2	—	x	1.5	—	x	2.1	—
Acute nonlymphocytic leukemia	x	1.5	—	x	2.9	—	x	0.7	—	x	1.0	—
Acute myeloid leukemia	x	1.0		x	2.0	—	x	0.5	—	0	0.7	—
Chronic myeloid leukemia	0	0.4		0	0.8	—	0	0.2	—	0	0.3	—
Acute lymphoid leukemia	x	0.3	—	0	0.6	—	0	0.1	—	0	0.2	—
Chronic lymphoid leukemia	0	0.5	—	x	0.9	—	0	0.3	—	0	0.4	—
Other leukemia	0	0.5	—	x	1.0	—	0	0.3	—	0	0.4	—
Multiple myeloma and immunoproliferative Dx	x	1.3	—	x	2.4	—	x	0.7	—	0	0.9	—
Multiple myeloma	x	1.3	—	x	2.4	—	x	0.7	—	0	0.9	—
Myelodysplastic syndrome	0	0.2	—	0	0.3	—	0	0.1	—	0	0.1	—
Chronic myeloproliferative disease	0	0.2	—	x	0.3	—	0	0.1	—	0	0.1	—
Benign neoplasms	0	0.2	—	x	0.4	—	0	0.1	—	0	0.1	—
Dx of blood and blood-forming organs	x	0.7	—	x	1.3	—	0	0.3	—	0	0.4	—
Aplastic anemia	x	0.1		x	0.2	—	0	0.0	—	0	0.1	—
Endocrine/Nutritional/Metabolic Dx	5	8.8	0.57 (0.19–1.33)	12	16.5	0.73 (0.38–1.27)	x	4.1	—	6	5.8	1.03 (0.38–2.24)
Diabetes mellitus	x	6.6	—	9	12.2	0.74 (0.34–1.40)	x	3.2	—	6	4.5	1.35 (0.49–2.93)
Amyotrophic lateral sclerosis	0	1.0	—	x	1.9	—	x	0.5	—	0	0.6	—
Circulatory disease	56	78.1	0.72 (0.54–0.93)‡	91	140.6	0.65 (0.52–0.80)†	45	38.0	1.19 (0.87–1.59)	43	55.4	0.78 (0.56–1.05)
Cerebrovascular disease	5	9.2	0.54 (0.18–1.27)	10	16.7	0.60 (0.29–1.10)	6	4.3	1.39 (0.51–3.02)	x	6.8	—
Acute myocardial infarction	22	31.5	0.70 (0.44–1.06)	29	55.9	0.52 (0.35–0.74)†	20	15.7	1.27 (0.78–1.96)	14	22.2	0.63 (0.35–1.06)
Dx of arteries, arterioles, and capillaries	x	3.5	—	x	6.2	—	0	1.7	—	x	2.6	—
Aortic aneurysm	x	2.0	—	x	3.6	—	0	1.0	—	x	1.5	—
Respiratory disease	9	11.6	0.78 (0.35–1.47)	20	20.7	0.97 (0.59–1.50)	5	5.5	0.91 (0.30–2.12)	7	9.1	0.77 (0.31–1.59)
Chronic obstructive pulmonary Dx	x	4.2	—	6	7.2	0.84 (0.31–1.82)	x	2.1	—	5	3.5	1.41 (0.46–3.29)
Digestive disease	7	13.0	0.54 (0.22–1.11)	14	24.4	0.57 (0.31–0.96)‡	x	6.2	—	x	8.5	—
Cirrhosis of liver	5	7.7	0.65 (0.21–1.51)	10	14.5	0.69 (0.33–1.27)	x	3.8	—	x	4.9	—
Diseases of pancreas	x	0.7	—	0	1.3	—	0	0.3	—	x	0.4	—
Genitourinary disease	x	2.5	—	x	4.5	—	x	1.2	—	x	1.9	—
Kidney diseases	x	2.2	—	x	4.0	—	x	1.0	—	x	1.6	—
Accidents/Poisonings/Violence	33	55.2	0.60 (0.41–0.84)†	89	119.3	0.75 (0.60–0.92)†	21	18.9	1.11 (0.69–1.70)	19	30.8	0.62 (0.37–0.96)‡
Motor vehicle traffic accidents	14	14.2	0.99 (0.54–1.65)	29	31.3	0.93 (0.62–1.33)	9	4.8	1.87 (0.86–3.55)	6	8.0	0.75 (0.28–1.64)

TABLE 4. (Continued)

Cause of Death	Maintenance			Operations			Distribution			Miscellaneous Exposure		
	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)	Observed	Expected*	SMR (95% CI)
Motor vehicle nontraffic accidents	0	0.6	—	x	1.3	—	0	0.2	—	x	0.3	—
Water transport accidents	x	1.2	—	x	2.5	—	0	0.5	—	0	0.7	—
Air and space transport accidents	x	0.8	—	x	1.7	—	x	0.3	—	0	0.5	—
All other accidents	6	14.8	0.41 (0.15–0.89)‡	25	31.2	0.80 (0.52–1.18)	x	5.4	—	x	8.5	—
Suicide	10	18.8	0.53 (0.26–0.98)‡	19	40.7	0.47 (0.28–0.73)†	6	6.1	0.99 (0.36–2.16)	6	10.2	0.59 (0.22–1.28)

x Observations in the 1–4 observed range are not reported in accordance with disclosure rules of Statistics Canada.
SMR (95% CI), standardized mortality ratio (95% confidence interval).
*Expected deaths based on Canadian general population mortality rates.
†Statistically significant at $P < 0.01$.
‡Statistically significant at $P < 0.05$.

As expected, mesothelioma deaths were more evident in maintenance and operations jobs. Workers classified as ''operations'' had no other notable findings for mortality, with an overall SMR of 0.72 (95% CI = 0.65 to 0.80). On the contrary, workers in the maintenance category showed a slightly higher overall cancer mortality rate than expected [95 observed vs 86.5 expected, SMR = 1.10 (95% CI = 0.89 to 1.34)]. However, the total SMR was only 0.77 (95% CI = 0.67 to 0.88). A nonstatistically significant excess of bladder cancer (5 observed vs 1.7 expected) was observed in maintenance workers.

Distribution jobs showed an overall SMR of 1.00; thus, the expected ''healthy worker effect'' was not displayed in these workers. This was due to small but notable excesses in the most common causes of death. The SMR for all circulatory diseases was 1.19, while moderate excesses that were not typical of healthy employed populations were present for cerebrovascular disease: 6 versus 4.3, SMR = 1.39 (95% CI = 0.51 to 3.02) and acute myocardial infarction: 20 versus 15.7, SMR = 1.27 (95% CI = 0.78 to 1.96). However, neither SMR was statistically significant. Also, noteworthy was the SMR for motor vehicle accidents in these jobs (SMR = 1.87, 95% CI = 0.86 to 3.55), many of whom are drivers.

Mortality by Exposure Status

Table 5 summarizes SMRs according to a general indicator of exposure to any operations present across jobs and operating segments. Persons classified as nonexposed in Table 5 were never in an exposed job (ie, exclusively nonexposed). A worker who had any portion of their work history in any exposed job was classified as exposed.

There were still significant deficits in all-cause (SMR = 0.74) and all-cancer (SMR = 0.84) in exposed workers, but each SMR was higher than that in nonexposed workers (SMRs = 0.62 and 0.73 for all causes and all cancers, respectively). Mesothelioma was significantly elevated in exposed workers (SMR = 3.53, 95% CI = 1.30 to 7.69), while other nonsignificant elevations were seen for bladder cancer (SMR = 1.25, 95% CI = 0.60 to 2.29), rectal cancer (SMR = 1.12, 95% CI = 0.60 to 1.91), and air and space transport accidents (SMR = 1.61, 95% CI = 0.59 to 3.49). Notably, leukemia, colon cancer, NHL, and lung cancer were all below expectation. There were five AML cases resulting in an SMR of 1.00.

SMRs in nonexposed workers were generally unremarkable, with the exception of 10 ALS cases, which was a significant excess (SMR = 2.48, 95% CI = 1.19 to 4.56). Other nonsignificant elevations were observed for Hodgkin disease based on five cases (SMR = 2.42, 95% CI = 0.79 to 5.64) and follicular lymphoma based on nine cases (SMR = 1.30, 95% CI = 0.60 to 2.47).

Mortality by Hire Date

In order to assess time trends for different diseases, we also examined the cohort by hire date (1964 to 1974) and 1975+ (see Table S-1, Supplemental Digital Content 1, http://links.lww.com/JOM/A493). These two periods resulted in a similar number of expected deaths. Overall mortality SMRs decreased from 0.70 to 0.68 for the earlier versus later higher groups, likely to be a reflection of the healthy worker effect wearing off, as most of the decrease was due to circulatory diseases (SMR = 0.70 and 0.62) for earlier and later hire periods, respectively. Malignant neoplasms showed a relatively constant SMR over the earlier and later hire periods (SMR = 0.79 and 0.77, respectively). Mesothelioma risk had a significantly raised SMR of 5.14, based on six deaths in the 1975+ hire group. Some a priori' causes of death showed a modestly raised (nonsignificant) SMR in the earlier time period only, including follicular NHL (SMR = 1.27 based on 11 cases), AML (SMR = 1.36 based on seven cases), and multiple myeloma/immunoproliferative diseases (SMR = 1.14 based on eight cases). In

TABLE 5. Mortality Results for Canadian Petroleum Cohort (1964–2006): Exposed and Nonexposed (Men and Women Combined)

Cause of Death	Exposed			Nonexposed		
	Observed	Expected[*]	SMR (95% CI)	Observed	Expected[*]	SMR (95% CI)
All causes	1,010	1,357.5	0.74 (0.70–0.79)[†]	659	1,060.8	0.62 (0.58–0.67)[†]
Infective and parasitic disease (Dx)	10	36.1	0.27 (0.13–0.51)[†]	17	23.3	0.73 (0.43–1.17)
Acquired immune deficiency syndrome	5	22.0	0.23 (0.07–0.53)[†]	9	11.5	0.78 (0.36–1.48)
Malignant neoplasms (MN)	351	419.5	0.84 (0.75–0.93)[†]	282	388.5	0.73 (0.64–0.82)[†]
MN buccal cavity and pharynx	7	12.3	0.57 (0.23–1.17)	x	8.0	—
MN esophagus	12	13.7	0.88 (0.45–1.53)	5	8.3	0.60 (0.20–1.40)
MN stomach	14	16.1	0.87 (0.48–1.46)	10	11.9	0.84 (0.41–1.55)
MN large intestine except rectum	38	38.3	0.99 (0.70–1.36)	17	33.0	0.52 (0.30–0.82)[†]
MN rectum and rectosigmoid junction	13	11.6	1.12 (0.60–1.91)	6	8.9	0.67 (0.25–1.46)
MN liver	5	8.1	0.62 (0.20–1.44)	x	5.6	—
MN gallbladder	x	2.3	—	x	2.6	—
MN pancreas	17	21.3	0.80 (0.47–1.28)	16	17.8	0.90 (0.51–1.46)
MN nose/sinuses	x	0.7	—	0	0.5	—
MN bronchus and lung	100	129.3	0.77 (0.63–0.94)[†]	68	104.6	0.65 (0.51–0.82)[†]
MN bone	0	1.4	—	0	1.1	—
Malignant melanoma	5	8.5	0.59 (0.19–1.37)	x	7.0	—
MN of connective and other soft tissue	x	3.0	—	x	2.9	—
Mesothelioma	6	1.7	3.53 (1.30–7.69)[‡]	x	1.1	—
MN breast	x	5.6	—	40	45.3	0.88 (0.63–1.20)
MN cervix uteri	x	0.7	—	x	5.6	—
MN corpus uteri	0	0.2	—	x	1.8	—
MN Ovary/Fallopian tube/Broad ligament	x	1.3	—	12	11.4	1.05 (0.54–1.83)
MN prostate	17	18.0	0.95 (0.55–1.52)	7	8.9	0.78 (0.32–1.61)
MN testis	x	1.5	—	x	0.7	—
MN kidney	9	12.1	0.74 (0.34–1.41)	6	8.8	0.68 (0.25–1.49)
MN bladder	10	8.0	1.25 (0.60–2.29)	x	5.3	—
Nervous system malignant, benign, and unspecified	20	21.2	0.94 (0.58–1.45)	16	17.5	0.91 (0.52–1.49)
All brain tumors	18	20.2	0.89 (0.53–1.41)	15	16.5	0.91 (0.51–1.50)
MN – Brain	17	18.0	0.95 (0.55–1.52)	14	14.6	0.96 (0.52–1.61)
MN CNS tumors (excluding brain)	x	0.4	—	x	0.4	—
MN site unknown	16	19.3	0.83 (0.47–1.35)	12	17.4	0.69 (0.36–1.20)
Hodgkin disease	x	2.7	—	5	2.1	2.42 (0.79–5.64)
Non-Hodgkin lymphoma	16	17.4	0.92 (0.53–1.49)	11	14.2	0.77 (0.39–1.38)
Diffuse non-Hodgkin lymphoma	8	9.2	0.87 (0.38–1.72)	7	7.3	0.96 (0.39–1.97)
Follicular non-Hodgkin lymphoma	9	8.7	1.04 (0.47–1.97)	9	6.9	1.30 (0.60–2.47)
Leukemias	12	15.7	0.77 (0.40–1.34)	11	12.9	0.85 (0.43–1.53)
Acute nonlymphocytic leukemia	6	7.2	0.83 (0.30–1.81)	x	6.4	—
Acute myeloid leukemia	5	5.0	1.00 (0.33–2.34)	x	4.4	—
Chronic myeloid leukemia	x	2.0	—	0	1.6	—
Acute lymphoid leukemia	x	1.3	—	x	1.2	—
Chronic lymphoid leukemia	x	2.6	—	x	1.7	—
Other leukemia	x	2.6	—	x	2.0	—
Multiple myeloma and immunoproliferative Dx	7	6.5	1.07 (0.43–2.21)	5	5.4	0.93 (0.30–2.16)
Multiple myeloma	x	6.4	—	5	5.3	0.94 (0.30–2.19)
Myelodysplastic syndrome	x	1.0	—	0	0.7	—
Chronic myeloproliferative disease	x	0.9	—	x	0.7	—
Benign neoplasms	x	1.0	—	0	1.1	—
Disease of blood and blood-forming organs	x	3.3	—	x	3.0	—
Aplastic anemia	x	0.5	—	0	0.5	—
Endocrine/Nutritional/Metabolic disease	31	42.6	0.73 (0.50–1.03)	9	34.0	0.27 (0.12–0.50)[†]
Diabetes mellitus	25	32.1	0.78 (0.50–1.15)	8	25.4	0.32 (0.14–0.62)[†]
Amyotrophic lateral sclerosis	5	4.8	1.04 (0.34–2.43)	10	4.0	2.48 (1.19–4.56)[‡]
Circulatory disease	273	376.4	0.73 (0.64–0.82)[†]	153	261.5	0.59 (0.50–0.69)[†]
Cerebrovascular disease	31	46.7	0.67 (0.46–0.94)[‡]	25	41.5	0.60 (0.39–0.89)[†]
Acute myocardial infarction	93	148.3	0.63 (0.51–0.77)[†]	44	93.0	0.47 (0.34–0.64)[†]
Diseases of arteries, arterioles, and capillaries	10	17.2	0.58 (0.28–1.07)	10	12.3	0.81 (0.39–1.50)
Aortic aneurysm	8	10.0	0.80 (0.35–1.58)	6	6.5	0.92 (0.34–2.00)
Respiratory disease	43	59.2	0.73 (0.53–0.98)[‡]	22	48.6	0.45 (0.28–0.69)[†]
Chronic obstructive pulmonary disease	16	22.1	0.73 (0.41–1.18)	8	17.9	0.45 (0.19–0.88)[‡]
Digestive disease	38	61.6	0.62 (0.44–0.85)[†]	30	46.4	0.65 (0.44–0.92)[‡]
Cirrhosis of liver	23	35.7	0.65 (0.41–0.97)[‡]	16	24.8	0.65 (0.37–1.05)
Diseases of pancreas	x	3.1	—	x	2.2	—
Genitourinary disease	8	12.6	0.63 (0.27–1.25)	6	10.8	0.55 (0.20–1.21)
Kidney diseases	8	11.1	0.72 (0.31–1.42)	x	9.3	—
Accidents/Poisonings/Violence	184	254.5	0.72 (0.62–0.84)[†]	75	166.6	0.45 (0.35–0.56)[†]

TABLE 5. (*Continued*)

Cause of Death	Exposed			Nonexposed		
	Observed	Expected[*]	SMR (95% CI)	Observed	Expected[*]	SMR (95% CI)
Motor vehicle traffic accidents	65	65.4	0.99 (0.77–1.27)	20	44.3	0.45 (0.28–0.70)[†]
Motor vehicle nontraffic accidents	x	2.7	—	0	1.5	—
Water transport accidents	x	5.4	—	x	2.8	—
Air and space transport Accidents	6	3.7	1.61 (0.59–3.49)	x	2.1	—
All other accidents	46	68.4	0.67 (0.49–0.90)[†]	15	43.4	0.35 (0.19–0.57)[†]
Suicide	47	86.2	0.55 (0.41–0.73)[†]	35	55.7	0.63 (0.44–0.87)[†]

x Observations in the 1–4 observed range are not reported in accordance with disclosure rules of Statistics Canada.
SMR (95% CI), standardized mortality ratio (95% confidence interval).
[*]Expected deaths based on Canadian general population mortality rates.
[†]Statistically significant at $P < 0.01$.
[‡]Statistically significant at $P < 0.05$.

addition, all central nervous system tumors (the vast majority being brain cancer) showed a higher SMR in the early hire period (SMR = 1.24 based on 25 cases). In contrast, a few causes of death showed a moderately raised, nonsignificant SMR only in the later hire period, including malignant neoplasms of the rectum and rectosigmoid junction (SMR = 1.15 based on 10 cases) and ovary (SMR = 1.62, based on nine cases).

Mesothelioma

The tenth revision of the ICD, in effect from 2000, designates a single code for mesothelioma; thus, mortality and incidence reporting are less complicated. As excess mesothelioma has been noted previously in this cohort, we also examined death certificates that could contain the diagnosis in previous versions of the ICD, as we did in the previous updates of this cohort.[9,11,12] This yielded five additional cases of mesothelioma, four of which were noted in the last update. In addition, the cohort was matched to cancer registry files maintained by SC. This yielded a sixth additional case of mesothelioma. These six cases, along with the nine cases identified from 2000 forward, yielded 15 cases of mesothelioma. Canadian rates assembled in the same manner as case ascertainment techniques yielded an expected number of 5.4 cases for a standardized incidence ratio (SIR) of 2.79 (95% CI = 1.56 to 4.60) (Table 6).[15] Subtracting the cases observed in the previously studied observation period yields 11 cases observed versus 4.12 expected for an SIR of 2.67. As previously noted, the mortality-only cases observed from

year 1999 forward yielded nine cases and an SMR of 3.27 (95% CI = 1.50 to 6.21).

These 15 cases were further reviewed. As for jobs and duration employed, 10 were in maintenance or operations jobs and worked from 11 to 32 years. As mesothelioma often develops decades after first exposure, the time between death/incidence and first employment was examined. Less than five subjects had a 10 to 14-year interval. Most had either a 15 to 24-year or 25 to 38-year interval. All subjects died or were diagnosed in their 50s and 60s; 10 at ages 50 to 59 years, and five at ages 61 to 63 years. Eleven of the 15 cases were employed in the refinery operating segment. There was only 1.0 expected case in the refinery segment, for a significant SIR of 10.9 (95% CI = 5.45 to 19.5).

We also examined SMRs for mesothelioma by age at hire, as employees hired later may have had exposure in other industries (see Table 6). Of the nine mortality cases, five were hired between ages 25 and 35 years (SMR = 4.89, 95% CI = 1.59 to 11.41). This analysis indicates that mesothelioma cases had some potential for exposures before employment in this company.

Lost to Follow-up

We needed to use a stratified random sampling technique to select 3564 lost to follow-up (LTF) employees. SC had determined that this was the correct number of LTF, but privacy laws prevented their direct identification. Instead, we examined DLO status in the original 6171 LTF employees and selected the 3564 employees to

TABLE 6. Mesothelioma Risk for a Canadian Petroleum Cohort by Hire Period/Age

Time Period	Characteristics	Observed	Expected	SIR/SMR	95% CI
1964–2006	Total cohort	15	5.40	(SIR) 2.79	1.56–4.60
1964–1994[†]	Total cohort	x	1.32	—	—
1995–2006	Total cohort	11	4.12	(SIR) 2.67	1.40–4.64[*]
1964–2006	Age < 45	x	0.4	—	—
	Age 45–54	x	1.6	—	—
	Age 55–64	11	2.2	(SIR) 5.00	2.63–8.69[*]
	Age 65+	x	1.2	—	—
1999–2006	Total cohort	9	2.8	(SMR) 3.27	1.50–6.21
	Hire age < 25	x	0.7	—	—
	Hire age 25–35	5	1.0	(SMR) 4.89	1.59–11.41
	Hire age > 35	x	1.0	—	—

x Observations in the 1–4 observed range are not reported in accordance with disclosure rules of Statistics Canada.
95% CI, 95% confidence interval; SIR, standardized incidence ratio; SMR, standardized mortality ratio.
[*]Calculated using Mid-*P* exact test.[15]
[†]Reference.[12]

TABLE 7. Sensitivity Analyses for Treatment of Lost-to-Follow-Up Employees

	3,564 LTF (Base Case)	6,171 LTF (Minimum PYAR)	DLO = End of Study (Maximum PYAR)
Number at risk	29,379	29,379	29,379
Person-years	702,905.7	664,287.9	748,166.5
Observed – All causes	1,669	1,669	1,669
Expected – All causes	2,418.5	2,384.0	2,619.5
SMR – All causes	0.690	0.700	0.637
Observed – All cancers	633	633	633
Expected – All cancers	808.0	803.2	885.1
SMR – All cancers	0.783	0.788	0.716

DLO, date last observed; LTF, lost to follow-up; PYAR, person-years at risk; SMR, standardized mortality ratio.

reflect this DLO distribution. We suspected that this strategy would yield the most similar overall SMR to an SMR calculated using the DLO for the 6171 employees. To examine this directly, we computed overall (all causes) and cancer SMRs for two additional scenarios, which we believed represented two extremes: (1) using the original 6171 workers as LTF and removing them from follow-up on their DLO (to produce a minimum number of person-years at risk, hence a lower expected number of deaths and higher SMR), and (2) treating all LTF workers as alive until the end of the study (to produce a maximum number of person-years at risk, hence a larger expected number of deaths and lower SMR). Strategy (1) could be justified, as it represents the usual treatment of LTF, while strategy (2) could be justified by the high sensitivity of the Canadian Mortality Database used by SC to identify deaths.[16] Results are summarized in Table 7.

These results show that the all-cause SMR for the baseline scenario (3564 LTF) is within 1.4% of the all-cause SMR, which treats all 6171 employees as LTF on their DLO. On the contrary, treating all LTF employees as alive until the end of the study would have reduced the SMR by 7.7% (from 0.690 to 0.637). Cancer SMRs show similar percent changes.

Finally, as the sensitivity of CMDB has been tested for its ability to identify deaths, one could also assume that this sensitivity (97.6%) applies to this cohort. This would predict that 1710, rather than 1669 deaths occurred. Applying the 1710 deaths to strategy (2) would yield an SMR of 0.653, a 5.4% lower SMR than the baseline approach.

DISCUSSION

This mortality update for a large Canadian cohort of petroleum workers was based on 16% more workers and 78% additional person-years of observation, allowing a better assessment of risks in this population. However, this is still a young population; thus, the accuracy of risk estimation, especially for rarer causes of death, is still relatively low. The percentage of deaths increased from 2% to 5.7% in this update. We believe it is advantageous to study inception cohorts (in this case, workers hired in 1964 or later) to improve the applicability to current workplace settings and to lessen the possibility of survivor bias influences on the results.[17]

As in many occupational cohort studies, mortality rates among working employees were compared with general population mortality rates; thus, the well-known healthy worker effect is probable. As this cohort is young, the healthy worker effect is greater, as more workers were close to their "selection date," which assured a health status sufficient to apply for and be selected for employment. Thus, even moderate, nonsignificant excesses should be viewed more critically for these workers.

While effects of gender and time period were controlled, we had no additional information on lifestyle habits such as drinking and smoking, which can affect mortality from several diseases. The study is also limited by its reliance on surrogates of exposure (eg, duration of employment, operating segment, job type, and general exposure to operations), and as such, excesses restricted to employees only exposed to select compounds may be missed.

Another limitation of this study is the potential LTF for 3564 workers. This is a somewhat larger percentage than usual. We not only used the Canadian Mortality Database, but also used the US NDI to identify deaths to account for people emigrating from Canada to the US who subsequently died. We also benefited from alive tracing performed at SC, which did reduce the number of LTF, but was somewhat compromised by an inability to directly identify which employees were successfully traced. Instead, we needed to select remaining LTF employees utilizing a stratified random sampling approach. We performed sensitivity analyses on this aspect of the study and showed that our estimate of the total SMR was likely to be bounded by an error from -1.4% to +7.7%. We proffer two reasons why the LTF percent is somewhat higher than normal: (1) there could be an increase in movement of workers between this Canadian affiliate and other affiliates from the same company outside of the US, and (2) there could be an increase in the number of short-term workers, as younger persons are frequently more mobile than in years past. Subsequent updates of this cohort will need to employ even more rigorous tracing techniques to limit LTF to more customary levels.

Cancer incidence data were requested for this study but were found to be unreliable, apparently due to the multiple ICD revisions these data cover. We hope to resolve this with Statistics Canada so that future analyses can examine incident cancers.

The mortality findings in the cohort overall continue to show favorable results, with an all-cause SMR of 0.69, slightly higher than the 0.65 measured in the previous update.[12] We expect that the all-cause SMR will continue to increase, as the survival advantage of initial employment selection wears off. Decreased mortality was primarily due to respiratory and circulatory diseases (especially acute myocardial infarction), which are commonly noted as most affected by the healthy worker selection effect. There were also very low SMRs for acquired immune deficiency syndrome and infectious and parasitic diseases.

For most *a priori* causes, results were not significantly elevated. Leukemia, NHL, and multiple myeloma showed unremarkable results, which is in agreement with most of the literature.[18] Malignant melanoma, which had been elevated in upstream workers in an earlier update of this cohort,[9] showed no excess risk in this update. Kidney, colon, and brain cancer were also not elevated for the full cohort or any subgroup examined.

In the last update, we reported an excess of gall bladder cancer based on less than five cases.[12] The present update found no new gall bladder cancer cases, while the expected number increased to 4.9.

The single finding that showed a clear excess in risk was for mesothelioma. With an additional follow-up of this inception cohort, the mesothelioma risk in workers hired post-1964 is clearer (Table 6). Overall, the present cohort found 11 additional cases for an overall SIR of 2.79[15] through 2006.

This two to three-fold risk of mesothelioma continues to persist despite continued attention in the company on asbestos exposure control. The risk is higher for maintenance and operations workers, and in the refining sector, where there is more potential for asbestos exposure. Approximately one-third of the mesothelioma cases had latency periods from first employment between 25 and 38 years, which translates to first exposures between 1968 and 1981. Although the risk of mesothelioma was expected to decrease by 2006, we did note that most decedents started work with the company at an age which suggests that they were previously employed elsewhere. If they were employed in prior jobs with asbestos exposure, the latency observed in this cohort could be artificially shortened.

A two-fold nonsignificant elevation of ALS was associated with a previous update of this study.[11] This update again reports a nonsignificant elevation of ALS, based on 15 cases (SMR = 1.70), which did not quite reach statistical significance. The etiology of ALS is largely unknown.[19,20] It appears that there is no clustering of ALS risk in this study by operating segment. A significant excess of ALS was found in nonexposed workers, which argues against an occupational etiology.

Other findings, some of which did not achieve statistical significance, should not be ignored, as the healthy worker effect is likely operating in this population. A near significant SMR for motor vehicle accidents among distribution workers likely reflects increased time in motor vehicles. The fact that maintenance workers show an all-cancer SMR greater than 1 is also unusual in an employed population. Bladder cancer rates should be monitored in this group, as they are subject to unique work environments (eg, welding, degreasing, etc).

In summary, this study yielded several useful insights on risks for this large Canadian cohort of petroleum workers. The clearest finding was a continuing excess of mesothelioma, which was predicted to decrease in this update. The excess concentrated in refinery workers and maintenance trades, who have a higher potential for asbestos exposure. A nonsignificant excess of ALS was also noted, which achieved significance only in workers not exposed to operations. A nonsignificant excess of motor vehicle traffic accidents in distribution workers may have an occupational link that should be monitored. Continued surveillance of this cohort is expected to yield more insight on these findings.

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