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An ecological study of cancer incidence in Port Hope, Ontario from 1992 to 2007

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Abstract
A plant processing radium and uranium ores has been operating in the town of Port Hope since 1932. Given the nuclear industry located in the community and ongoing public health concerns, cancer incidence rates in Port Hope were studied for a recent 16 year period (1992–2007) for continued periodic cancer incidence surveillance of the community. The cancer incidence in the local community for all cancers combined was similar to the Ontario population, health regions with similar socio-economic characteristics in Ontario and in Canada, and the Canadian population. No statistically significant differences in childhood cancer, leukaemia or other radiosensitive cancer incidence were observed, with the exception of statistically significant elevated lung cancer incidence among women. However, the statistical significance was reduced or disappeared when the comparison was made to populations with similar socio-economic characteristics. These findings are consistent with previous ecological, case-control and cohort studies conducted in Port Hope, environmental assessments, and epidemiological studies conducted elsewhere on populations living around similar facilities or exposed to similar environmental contaminants. Although the current study covered an extended period of time, the power to detect risk at the sub-regional level of analysis was limited since the Port Hope population is small (16 500). The study nevertheless indicated that large differences in cancer incidence are not occurring in Port Hope compared to other similar communities and the general population.

(Some figures may appear in colour only in the online journal)

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1. Introduction

The Port Hope Conversion Facility (PHCF) was established in Port Hope, Ontario in 1932. The PHCF was initially established to extract radium from high-grade pitchblende ores; in 1942 the focus shifted from processing of radium to processing of uranium. After 1966 only purified feed material (yellow cake) was processed at the PHCF. Beginning in 1983 operational changes were implemented which resulted in lower overall atmospheric emissions of radionuclides. Since the mid-1980s emissions have primarily been natural uranium.

As a result of public concerns about the historic disposal of low-level radioactive waste throughout the town and the use of contaminated fill at various construction sites in the area, a massive remedial action was undertaken in Port Hope from 1976 to 1981. Contaminated soils were removed from homes with radon levels above 150 Bq m^{-3}.

In 1994, a dose reconstruction project was undertaken to assess the cumulative radiation exposure (1955–1993) to typical residents of Port Hope resulting from 40 yr of exposure to the uranium industry [1]. The largest doses to Port Hope residents were due to indoor radon and gamma radiation exposures. From 1955 to 1993, the annual average dose rate to Port Hope residents from exposure to indoor gamma radiation ranged from 0.27 to 0.25 mSv yr^{-1} and from 0.99 to 0.69 mSv yr^{-1} from exposure to indoor radon. From 1981 to 1982, uranium in air concentrations in Port Hope around the PHCF had a geometric mean of 0.02 μgU m^{-3}, resulting in an annual committed effective dose of 0.16 mSv [2]. Following operational improvements starting in 1983, uranium emissions were significantly reduced and in 1988 to 1989 the geometric mean uranium in air concentration was 0.001 05 μgU m^{-3} [3]; equivalent to an annual committed effective dose $<$0.008 mSv. In 2007, the annual dose from the PHCF emissions was conservatively estimated for the most exposed member of the public (critical group) to be around 0.064 mSv [4]. Based on these low cumulative estimated exposures and existing scientific knowledge of radiation risk [5–7], an observable excess of cancer would not be expected relative to the Canadian population.

In 2000, Health Canada conducted an ecological study to compare cancer incidence rates (1971–1996) for the town of Port Hope to the general Ontario population and four similar Ontario communities [8]. This study period overlaps with the period of higher emissions (pre-1984) and the partial clean up of contaminated areas (1976–1981). The study found the cancer incidence for all cancers combined in Port Hope was similar to the comparison communities and the general Ontario population. The absence of significant differences in overall leukaemia incidence or other radiosensitive cancer sites was reassuring and did not support the hypothesis that radiation exposures in the community impacted the health of residents. No difference in childhood (0–19 yr) leukaemia was also reassuring, as the minimum latency for childhood leukaemia is short and the radiation risk coefficients relatively high. There were some statistically significant high and low results when the analysis was by age group, sex, time period and residence coding; however, overall there was no pattern of increased cancer risks. This conclusion is supported by a recent study using a weight of evidence approach of more than 30 environmental risk assessments and 13 epidemiological studies conducted in Port Hope [9, 10]. These findings are consistent with the international scientific understanding of the effects on human health of radiation and uranium toxicity [5–7, 11]. The Port Hope findings also were consistent with the results of epidemiological studies conducted on uranium processing workers and the public near uranium mines, mills, and processing facilities [5, 6, 12–26].

Cancer incidence rates are revisited in Port Hope for a recent 16 yr period (1992–2007) corresponding to the period of significantly reduced plant emissions and ending before the start of the planned remediation of the remaining contaminated areas in the municipality of Port

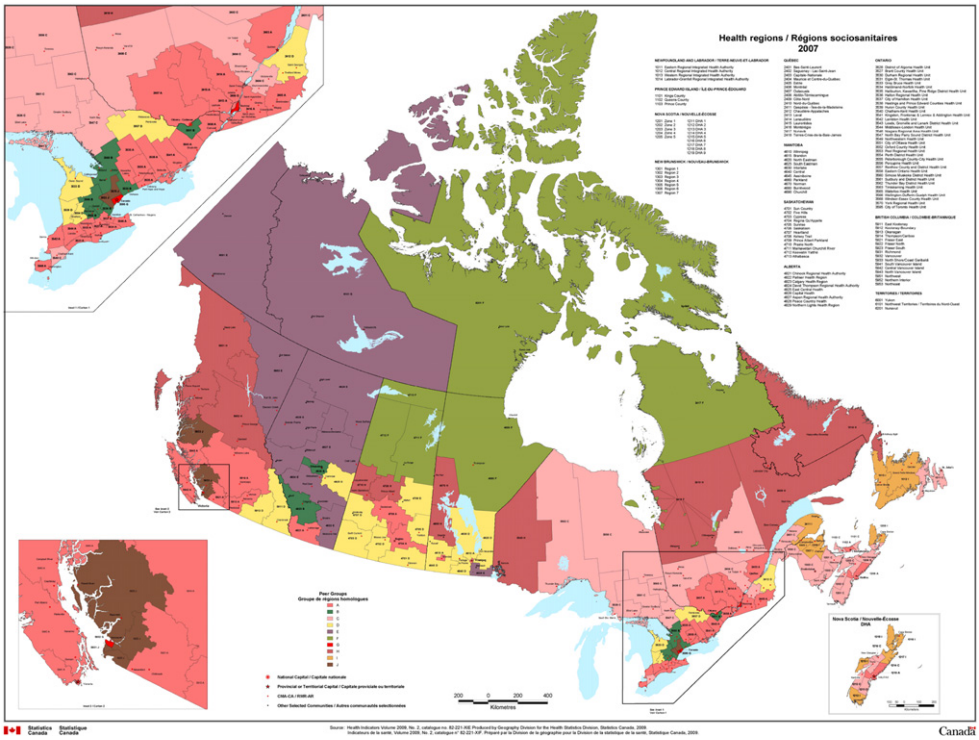

Figure 1. Health regions and peer groups in Canada [27].

Hope. The first 5 yr (1992–1996) overlap with the previous study. In addition, the current study compares cancer incidence rates in Port Hope to those of the Ontario population, health regions of similar social and economic characteristics in Ontario and in Canada, and the Canadian population.

2. Methods

Canada is divided into 123 health regions defined by the provincial ministries of health as administrative areas. Health regions were grouped into peer groups in order to effectively compare health regions with similar socio-economic characteristics [27]. Statistics Canada used a statistical method to determine peer groups and assign health regions to peer groups to achieve maximum statistical differentiation between health regions. Twenty-four variables were chosen to cover as many of the social and economic determinants of health as possible, using data collected at the health region level mostly from the Census of Canada. Concepts covered included basic demographics (for example, population change and demographic structure), living conditions (for example, socio-economic characteristics, housing, and income inequality), and working conditions (for example, labour market conditions). A summary of peer groups and principal characteristics is given in table 1. There are currently ten peer groups identified by letters A through J, as shown in figure 1.

The Canadian Cancer Registry (CCR) is an administrative survey that collects information on cancer incidence in Canada [28]. Its primary objective is to provide a large database to study cancer patterns and trends and to monitor differences in cancer risks among different

Table 1. Summary table of peer groups and principal characteristics [27].

Peer group	Number of health regions	Percentage of Canadian population (%)	Principal characteristics
A	35	33.5	• Urban–rural mix from coast to coast • Average percentage of Aboriginal population • Average percentage of immigrant population
B	8	16.7	• Mainly urban centres in Ontario and Alberta with moderately high population density • Low percentage of Aboriginal population • Very high employment rate • Higher than average percentage of immigrant population
C	22	10.3	• Sparsely populated urban–rural mix in Eastern and Central provinces • Average percentage of Aboriginal population • Average employment rate • Low percentage of immigrant population
D	18	5.1	• Mainly rural regions from Quebec to British Columbia • Average percentage of Aboriginal population • High employment rate
E	9	3.1	• Mainly rural and remote regions in the Western provinces and the Territories • High proportion of Aboriginal population • Average percentage of immigrant population
F	5	0.4	• Northern and remote regions • Very high proportion of Aboriginal population • Very low employment rate • Low proportion of immigrants
G	3	15.6	• Largest metro centres with an average population density of 4065 people km^{-2} • Very low proportion of Aboriginal population • Average employment rate • Very high proportion of immigrant population
H	10	2.0	• Rural northern regions from coast to coast • High proportion of Aboriginal population • Low proportion of immigrants
I	7	1.7	• Mainly rural Eastern regions • Average percentage of Aboriginal population • Low employment rate • Very low percentage of immigrant population
J	6	11.6	• Mainly urban centres in Ontario and British Columbia with high population density • Low proportion of Aboriginal population • High proportion of immigrants

populations. All primary malignant tumours (except squamous cell skin cancer and basal cell skin cancer) are reported to the CCR. The CCR is a collaborative effort between the thirteen Canadian provincial and territorial cancer registries and the Health Statistics Division of Statistics Canada, where the data are housed. Ultimate authority and responsibility for the degree of coverage and the quality of the data reside with the provinces and territories.

The data that comes into the CCR describe both, the individual with the cancer and the characteristics of the cancer. The CCR is a dynamic database of all Canadian residents alive or dead who have been diagnosed with cancer. The function of the CCR is to produce standardised and comparable cancer incidence and survival data for each primary site of cancer. The CCR is a

patient-based system, in which the kind and number (incidence) of primary cancers diagnosed for each person until death are recorded. The advantage of this system is that longitudinal data are available for each cancer patient. The patient data are regularly linked to mortality data so that the date and cause of death of every cancer patient is eventually known. Since each Canadian province and territory has a legislated responsibility for cancer collection and control, reporting is virtually complete. Statistics Canada provides detailed feedback on the quality of data submitted each year, and provincial and territorial cancer registries investigate the completeness of case ascertainment through regular assessments.

Cancer incidence data collected by the CCR, covering the period from 1992 to 2007, were obtained and summarised for the municipality of Port Hope, the Ontario population, health regions in Peer Group A in Ontario (excluding health regions with nuclear power plants), health regions in Peer Group A outside of Ontario (excluding British Columbia since geocoded data below provincial level are not available on the current cancer incidence file at Health Canada for British Columbia), and the Canadian population in all 123 health regions. There are a total of five nuclear power plants in Canada (3 in Ontario, 1 in Quebec and 1 in New Brunswick). Health regions containing nuclear power plants were excluded from the Peer Group A analyses, to remove any public concerns that their inclusion may bias the Peer Groups. However, radiation emissions from these plants are orders of magnitude (a few μSv yr^{-1}) below the public dose limit (1 mSv yr^{-1}) and background levels of radiation exposure. To date, studies provide no evidence that routine radiation emissions from these plants are related to increased risk of cancer among people living nearby [29–33].

Information was obtained for all cancers combined, cancer of the thyroid, lung and bronchus, breast, ovary, stomach, colon (excluding rectum), bladder, brain, and liver, and leukaemia, non-Hodgkin's lymphoma (NHL), and melanoma of the skin since these cancer sites are sensitive to radiation [5, 34, 35]. Disease coding is based on the 3rd edition of the International Classification of Diseases for Oncology [36]. Cases coded to the second edition were converted.

Observed and expected incident cancer cases were presented by sex (for men and women separately and combined), by age groups (0–24, 15–64, 65–85+ yr), by all ages combined (0–85+ yr), and by period (1992, 1993–1997, 1998–2002, 2003–2007) and for the combined period (1992–2007). Standardised incidence ratios (SIRs) with 95% confidence intervals (CIs) were calculated. The SIR is defined as the number of cases observed divided by the number of cases expected based on age and sex-specific rates of the reference population for the corresponding period.

Because of confidentiality concerns, the present report restricts reporting for less than five cases, thus some of the combined values had to be suppressed to preserve confidentiality of components with less than 5 cases. The summary data were not presented for various age groups, as additional suppression of data would have been required and no further significant results for Port Hope would be included.

No counts for childhood cancer were available for Port Hope for the already extended age group 0–24 yr in this study. In order to provide analysis for children, we compared childhood leukaemia and NHL combined (age 0–14 yr) within the larger 25 km radius of the PHCF to the Ontario population from 1990 to 2008.

The power of this study depends on the number of expected cases. Table 7.2 given by Breslow and Day in Statistical Methods in Cancer Research [37] was used to calculate the power. Using Ontario as the reference population and the expected cases for leukaemia (all ages, both sexes combined) for example, the probability (%) of obtaining a result significant at the 0.01 level (one sided) of the expected value (E) of 40 (39.4 actual expected cases) assuming no excess risk, and of the true R (or SIR in our case), the sample power for $R = 1.5$ is 71%

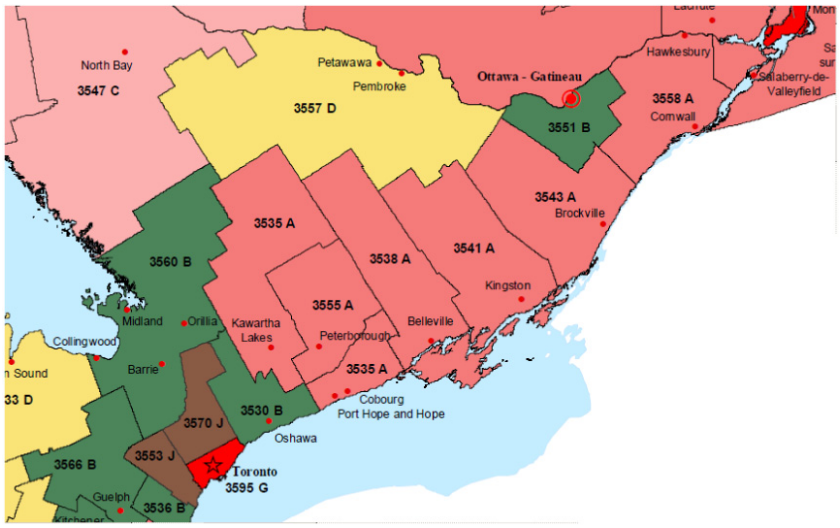

Figure 2. Location of Port Hope in Health Region 3535A [27].

and $R = 1.6$ is 86%. The power to detect a significant result for lung cancer in women, using Ontario as the reference population, $E = 80$ (77.5 actual expected cases), $R = 1.4$ is 81%.

The objective of this work was to conduct an ecological hypothesis-screening study [38] to provide updated cancer incidence data. The study compared the Port Hope population to 5 different reference populations:

- Reference 1—Ontario population.
- Reference 2—Health regions of Peer Group A in Ontario (excluding those health regions with nuclear power plants).
- Reference 3—Health regions of Peer Group A outside of Ontario (excluding British Columbia).
- Reference 4—Health regions in Peer Group A (i.e., combination of references 2 and 3).
- Reference 5—Canadian population.

3. Results

The municipality of Port Hope has a population of 16 500 [39]. The estimated population statistics show that 48% are men and 52% are women. About 22% of the population in Port Hope is under the age of 19 and the median age is 47 yr. Port Hope belongs to Health Region 3535 and Peer Group A, as shown in figure 2. Peer Group A contains 35 health regions and represents the largest peer group, representing 33.5% of the Canadian population. The principal characteristics of Peer Group A include mixed urban–rural from coast to coast, average percentage of aboriginal population, and average percentage of immigrant population.

Results of the comparisons between cancer incidence in Port Hope and other reference populations are summarised in tables 2–5. In the summary tables, a blank in the number of cases column indicates that the number of cases is less than 5 and, therefore, not reported. SIRs are not calculated for these cancer sites because of the high degree of variability in risk estimates when using small numbers.

Table 2. Cancer incidence 1992–2007 for Port Hope in reference to Ontario population by sex.

Cancer site	Gender	Number of cases	Expected	SIR	95% CI	SIR flag
All cancers	Men	714	692.5	1.03	[0.96, 1.11]	
	Women	649	636.3	1.02	[0.94, 1.10]	
	Combined	1363	1330.6	1.02	[0.97, 1.08]	
Leukaemias	Men	21	22.3	0.94	[0.58, 1.44]	
	Women	13	17.1	0.76	[0.40, 1.30]	
	Combined	34	39.4	0.86	[0.60, 1.21]	
Non-Hodgkin's lymphomas	Men	28	28.6	0.98	[0.65, 1.42]	
	Women	18	25.5	0.71	[0.42, 1.11]	
	Combined	46	54.1	0.85	[0.62, 1.13]	
Thyroid	Men		5.8			
	Women	11	20.1	0.55	[0.27, 0.98]	−
	Combined		25.9	<1.0		
Lung and bronchus	Men	121	105.1	1.15	[0.96, 1.38]	
	Women	109	77.5	1.41	[1.16, 1.70]	++
	Combined	230	182.8	1.26	[1.10, 1.43]	++
Stomach	Men	16	17.5	0.91	[0.52, 1.48]	
	Women	10	10.5	0.95	[0.46, 1.76]	
	Combined	26	28.0	0.93	[0.61, 1.36]	
Colon excluding rectum	Men	62	62.3	0.99	[0.76, 1.28]	
	Women	73	64.4	1.13	[0.89, 1.43]	
	Combined	135	126.7	1.07	[0.89, 1.26]	
Bladder	Men	38	33.7	1.13	[0.80, 1.55]	
	Women	10	12.1	0.82	[0.39, 1.52]	
	Combined	48	46.0	1.04	[0.77, 1.38]	
Brain	Men	9	10.8	0.84	[0.38, 1.59]	
	Women	9	8.8	1.02	[0.47, 1.94]	
	Combined	18	19.5	0.92	[0.55, 1.46]	
Liver	Men		7.3			
	Women		2.6			
	Combined		9.9			
Melanomas of the skin	Men	30	21.3	1.41	[0.95, 2.02]	
	Women	16	18.4	0.87	[0.50, 1.42]	
	Combined	46	39.6	1.16	[0.85, 1.55]	
Breast	Women	165	173.5	0.95	[0.81, 1.11]	
Ovary	Women	17	21.9	0.78	[0.45, 1.24]	

Note: standardised incidence ratio (SIR) flag: ++ significantly high, p-value < 0.01. + significantly high, p-value < 0.05. Blank not significant. − significantly low, p-value < 0.05. −− significantly low, p-value < 0.01.

Table 2 presents the comparison between Port Hope and the Ontario population (Reference 1). Overall, the incidence of all cancer combined in Port Hope from 1992 to 2007 was similar to the Ontario population (SIR = 1.02, 95% CI: 0.97, 1.08), based on 1363 observed and 1331 expected cases. No statistically significant differences in cancer risk were observed among men. However, lung cancer was elevated among men and women combined (SIR = 1.26, 95% CI: 1.10, 1.43, $p < 0.01$) which was dominated by elevated lung cancer among women (SIR = 1.41, 95% CI: 1.16, 1.70, $p < 0.01$) based on 109 observed and 78 expected cases. The thyroid cancer rate was decreased among Port Hope women (SIR = 0.55, 95% CI: 0.27, 0.98, $p < 0.05$) based on 11 observed and 20 expected cases. Finally, from 1990 to 2008, no statistically significant difference in cancer risk were observed for leukaemia and NHL combined for children age 0–14, diagnosed within the 25 km radius of the PHCF (SIR = 1.01, 95% CI: 0.52–1.76) based on 12 observed and 11.9 expected cases (not shown). Further breakdown was not available because of the very small number of cases.

Table 3. Cancer incidence 1992–2007 for Port Hope in reference to health regions of Peer Group A in Ontario excluding those health regions with nuclear power plants by sex.

Cancer site	Gender	Number of cases	Expected	SIR	95% CI	SIR flag
All cancers	Men	714	710.6	1.00	[0.93, 1.08]	
	Women	649	641.4	1.01	[0.94, 1.09]	
	Combined	1363	1353.8	1.01	[0.95, 1.06]	
Leukaemias	Men	21	22.4	0.94	[0.58, 1.43]	
	Women	13	17.2	0.76	[0.40, 1.29]	
	Combined	34	39.7	0.86	[0.59, 1.20]	
Non-Hodgkin's lymphomas	Men	28	28.3	0.99	[0.66, 1.43]	
	Women	18	25.3	0.71	[0.42, 1.12]	
	Combined	46	53.6	0.86	[0.63, 1.14]	
Thyroid	Men		4.1			
	Women	11	13.0	0.85	[0.42, 1.51]	
	Combined		17.1	<1.0		
Lung and bronchus	Men	121	115.7	1.05	[0.87, 1.25]	
	Women	109	86.7	1.26	[1.03, 1.52]	+
	Combined	230	202.7	1.13	[0.99, 1.29]	
Stomach	Men	16	16.3	0.98	[0.56, 1.60]	
	Women	10	9.1	1.10	[0.53, 2.02]	
	Combined	26	25.4	1.02	[0.67, 1.50]	
Colon excluding rectum	Men	62	63.5	0.98	[0.75, 1.25]	
	Women	73	66.0	1.11	[0.87, 1.39]	
	Combined	135	129.5	1.04	[0.87, 1.23]	
Bladder	Men	38	35.1	1.08	[0.77, 1.49]	
	Women	10	12.8	0.78	[0.37, 1.43]	
	Combined	48	48.0	1.00	[0.74, 1.33]	
Brain	Men	9	10.9	0.83	[0.38, 1.57]	
	Women	9	9.2	0.98	[0.45, 1.86]	
	Combined	18	20.1	0.90	[0.53, 1.42]	
Liver	Men		6.1			
	Women		2.0			
	Combined		8.1			
Melanomas of the skin	Men	30	23.1	1.30	[0.87, 1.85]	
	Women	16	19.3	0.83	[0.47, 1.35]	
	Combined	46	42.4	1.08	[0.79, 1.45]	
Breast	Women	165	173.8	0.95	[0.81, 1.11]	
Ovary	Women	17	22.4	0.76	[0.44, 1.21]	

Note: standardised incidence ratio (SIR) flag: ++ significantly high, p-value < 0.01. + significantly high, p-value < 0.05. Blank not significant. − significantly low, p-value < 0.05. −− significantly low, p-value < 0.01.

Table 3 presents the comparison between Port Hope and health regions of Peer Group A in Ontario, excluding those health regions with nuclear power plants (Reference 2). Similar to table 2, the incidence of all cancer combined in Port Hope was similar to the reference group and no differences in cancer incidence were observed among men. Lung cancer was elevated among women (SIR = 1.26, 95% CI: 1.03, 1.52, $p < 0.05$).

Table 4 presents the comparison between Port Hope and all health regions of Peer Group A in Canada, excluding those health regions with nuclear power plants (Reference 4). Similar to tables 2 and 3, the incidence of all cancer combined in Port Hope was similar to the reference group. No differences in cancer incidence were observed among women. Melanoma of the skin was elevated (SIR = 1.45, 95% CI: 1.06, 1.93, $p < 0.05$) among men and women combined compared to the reference group. This was dominated by elevated melanoma of the skin among

Table 4. Cancer incidence 1992–2007 for Port Hope in reference to health regions of Peer Group A in Canada excluding those health regions with nuclear power plants, by sex.

Cancer site	Gender	Number of cases	Expected	SIR	95% CI	SIR flag
All cancers	Men	714	731.5	0.98	[0.91, 1.05]	
	Women	649	655.7	0.99	[0.92, 1.07]	
	Combined	1363	1386.1	0.98	[0.93, 1.04]	
Leukaemias	Men	21	22.5	0.93	[0.58, 1.43]	
	Women	13	17.3	0.75	[0.40, 1.29]	
	Combined	34	39.7	0.86	[0.59, 1.20]	
Non-Hodgkin's lymphomas	Men	28	28.4	0.99	[0.66, 1.43]	
	Women	18	25.1	0.72	[0.42, 1.13]	
	Combined	46	53.4	0.86	[0.63, 1.15]	
Thyroid	Men		4.1			
	Women	11	12.4	0.89	[0.44, 1.59]	
	Combined		16.4	<1.0		
Lung and bronchus	Men	121	132.5	0.91	[0.76, 1.09]	
	Women	109	90.4	1.21	[0.99, 1.45]	
	Combined	230	222.5	1.03	[0.90, 1.18]	
Stomach	Men	16	18.1	0.88	[0.50, 1.43]	
	Women	10	10.7	0.94	[0.45, 1.72]	
	Combined	26	28.7	0.91	[0.59, 1.33]	
Colon excluding rectum	Men	62	62.8	0.99	[0.76, 1.27]	
	Women	73	65.6	1.11	[0.87, 1.40]	
	Combined	135	128.3	1.05	[0.88, 1.25]	
Bladder	Men	38	46.7	0.81	[0.58, 1.12]	
	Women	10	16.8	0.60	[0.29, 1.10]	
	Combined	48	63.2	0.76	[0.56, 1.01]	
Brain	Men	9	11.3	0.80	[0.36, 1.51]	
	Women	9	9.1	0.99	[0.45, 1.88]	
	Combined	18	20.4	0.88	[0.52, 1.40]	
Liver	Men		6.6			
	Women		2.4			
	Combined		9.0			
Melanomas of the skin	Men	30	17.1	1.76	[1.19, 2.51]	++
	Women	16	14.8	1.08	[0.62, 1.76]	
	Combined	46	31.8	1.45	[1.06, 1.93]	+
Breast	Women	165	176.5	0.93	[0.80, 1.09]	
Ovary	Women	17	22.0	0.77	[0.45, 1.24]	

Note: standardised incidence ratio (SIR) flag: ++ significantly high, p-value < 0.01. + significantly high, p-value < 0.05. Blank not significant. − significantly low, p-value < 0.05. −− significantly low, p-value < 0.01.

men (SIR = 1.76, 95% CI: 1.19, 2.51, $p < 0.01$). These findings differed from when the reference was made to the Ontario population, in tables 2 and 3.

Table 5 presents the comparison between Port Hope and the Canadian population (Reference 5). Similar to tables 2–4 the incidence of all cancer combined in Port Hope was similar to the reference group. Lung cancer was elevated among Port Hope women (SIR = 1.32, 95% CI: 1.08, 1.59, $p < 0.01$). Melanoma skin cancer was elevated among Port Hope men (SIR = 1.68, 95% CI: 1.14, 2.40, $p < 0.05$). Liver cancer was statistically significantly low among men and women combined, based on less than 10 cases.

Lung cancer incidence was further investigated for each 5 yr period from 1993 to 2007. Lung cancer incidence was only elevated (SIR = 1.56, 95% CI: 1.10, 2.15, $p < 0.5$), based on 37 observed and 24 expected cases among Port Hope women during the last 5 yr period (2003–2007) compared to the Ontario population (table 6, Reference 1). No differences in lung

Table 5. Cancer incidence 1992–2007 for Port Hope in reference to Canadian population, by sex.

Cancer site	Gender	Number of cases	Expected	SIR	95% CI	SIR flag
All cancers	Men	714	710.7	1.00	[0.93, 1.08]	
	Women	649	642.8	1.01	[0.93, 1.09]	
	Combined	1363	1358.4	1.00	[0.95, 1.06]	
Leukaemias	Men	21	21.7	0.97	[0.60, 1.48]	
	Women	13	16.6	0.78	[0.42, 1.34]	
	Combined	34	38.4	0.88	[0.61, 1.24]	
Non-Hodgkin's lymphomas	Men	28	28.2	0.99	[0.66, 1.44]	
	Women	18	25.0	0.72	[0.43, 1.14]	
	Combined	46	53.3	0.86	[0.63, 1.15]	
Thyroid	Men		4.8			
	Women	11	15.6	0.70	[0.35, 1.26]	
	Combined		20.4	<1.0		
Lung and bronchus	Men	121	119.0	1.02	[0.84, 1.21]	
	Women	109	82.6	1.32	[1.08, 1.59]	++
	Combined	230	202.4	1.14	[0.99, 1.29]	
Stomach	Men	16	18.8	0.85	[0.49, 1.38]	
	Women	10	11.3	0.88	[0.42, 1.63]	
	Combined	26	30.2	0.86	[0.56, 1.26]	
Colon excluding rectum	Men	62	60.1	1.03	[0.79, 1.32]	
	Women	73	62.7	1.16	[0.91, 1.46]	
	Combined	135	123.1	1.10	[0.92, 1.30]	
Bladder	Men	38	44.0	0.86	[0.61, 1.18]	
	Women	10	15.7	0.64	[0.30, 1.17]	
	Combined	48	60.1	0.80	[0.59, 1.06]	
Brain	Men	9	10.9	0.83	[0.38, 1.57]	
	Women	9	8.7	1.04	[0.47, 1.97]	
	Combined	18	19.6	0.92	[0.54, 1.45]	
Liver	Men		7.5			
	Women		2.9			
	Combined		10.3	<1.0		−
Melanomas of the skin	Men	30	17.8	1.68	[1.14, 2.40]	+
	Women	16	16.0	1.00	[0.57, 1.63]	
	Combined	46	33.8	1.36	[0.99, 1.81]	
Breast	Women	165	174.5	0.95	[0.81, 1.10]	
Ovary	Women	17	21.1	0.81	[0.47, 1.29]	

Note: standardised incidence ratio (SIR) flag: ++ significantly high, p-value < 0.01. + significantly high, p-value < 0.05. Blank not significant. − significantly low, p-value < 0.05. −− significantly low, p-value < 0.01.

cancer incidence for either men or women in Port Hope in each of the 5 yr periods was observed in comparison to the population of similar socio-economic characteristics (Peer Group A in Ontario, excluding those health regions with nuclear power plants) (table 7, Reference 2).

4. Discussion and conclusions

Overall, the incidence of all cancers combined in Port Hope from 1992 to 2007 was similar to the Ontario and Canadian population, and health regions with similar socio-economic characteristics. This overall finding was consistent with the Health Canada (2000) study [8], from 1971 to 1996. We found no consistent differences in the incidence of thyroid, breast, ovary, stomach, colon (excluding rectum), bladder, brain or liver cancer or leukaemia and non-Hodgkin's lymphoma among those aged 0–85+ yr. Importantly, we found no evidence

Table 6. Lung cancer incidence for Port Hope in reference to the Ontario population, by time period and sex.

Period	Sex	Number of cases	Expected	SIR	95% CI	SIR flag
1993–1997	Men	38	32.5	1.17	[0.83, 1.61]	
	Women	30	21.7	1.38	[0.93, 1.98]	
1998–2002	Men	41	31.2	1.31	[0.94, 1.78]	
	Women	32	24.1	1.33	[0.91, 1.87]	
2003–2007	Men	31	27.2	1.14	[0.77, 1.62]	
	Women	37	23.7	1.56	[1.10, 2.15]	+

Note: standardised incidence ratio (SIR) flag: ++ significantly high, p-value < 0.01. + significantly high, p-value < 0.05. Blank not significant. − significantly low, p-value < 0.05. −− significantly low, p-value < 0.01.

Table 7. Lung cancer incidence for Port Hope in reference to health regions of Peer Group A in Ontario excluding those health regions with nuclear power plants, by time period and sex.

Period	Sex	Number of cases	Expected	SIR	95% CI	SIR flag
1993–1997	Men	38	35.1	1.08	[0.77, 1.49]	
	Women	30	24.0	1.25	[0.84, 1.78]	
1998–2002	Men	41	34.8	1.18	[0.85, 1.60]	
	Women	32	27.3	1.17	[0.80, 1.65]	
2003–2007	Men	31	30.5	1.02	[0.69, 1.44]	
	Women	37	27.0	1.37	[0.97, 1.89]	

Note: standardised incidence ratio (SIR) flag: ++ significantly high, p-value < 0.01. + significantly high, p-value < 0.05. Blank not significant. − significantly low, p-value < 0.05. −− significantly low, p-value < 0.01.

of elevated childhood cancer (age 0–14) among those living within the 25 km radius of the PHCF. These findings are similar to the previous study [8] although some differences in cancer incidence were found previously, when data were divided into smaller groups by age group, sex, time period and residence coding.

There was evidence that melanoma skin cancer was elevated among Port Hope men compared to the Canadian population and Peer Group A in Canada. Melanoma has been underreported in Quebec [40]; therefore, Ontario is a better reference area than Canada. Elevated incidence rates were not observed compared to the Ontario population and Peer Group A in Ontario. No difference in incidence for malignant melanoma of the skin was observed in the previous study [8]. Exposure to sunlight (UV radiation) is the main risk factor for any type of skin cancer. Other risk factors include at least one severe blistering, lifetime sun exposure, and tanning [41].

We found elevated lung cancer incidence rates among Port Hope women from 1992 to 2007 compared to the Ontario and Canadian population and health regions with similar socio-economic characteristics in Ontario. Further investigation found that elevated lung cancer incidence was observed for all three 5 yr time periods; however it was only statistically significantly elevated in the most recent time period (2003–2007) compared to the Ontario population. No difference in lung cancer incidence was observed among men compared to any reference population or time period. These findings are similar to Health Canada's (2000) report which found an elevated lung cancer incidence among Port Hope women compared to the general Ontario population from 1986 to 1996 (SIR = 1.44; 95% CI: 1.06, 1.91) based on 47 cases. The 1971–1996 cancer incidence study [8] used the town boundary at the time, which included a smaller area than the current boundary since one township was amalgamated.

Although not an exact time and geographical area comparison, our study found elevated, but not statistically significant, lung cancer incidence among women from 1993 to 1997 (SIR = 1.38, 95% CI: 0.93, 1.98, $O = 30$, $E = 21.7$) compared to the Ontario population, which is similar to what was found previously [8]. According to tables 6 and 7, this excess seems to persist after 1996.

Tobacco smoking is the primary cause of lung cancer with relative risks for current smokers being greater than 10- to 20-fold higher than that of non-smokers [42, 43]. It is essential to consider the potential confounding impact of smoking on risk estimates. Other important risk factors are work and environmental exposures to radon and asbestos and personal history, such as having radiation therapy or a family history of lung cancer [43, 44]. The Haliburton, Kawartha, Pine Ridge (HKPR) District Health Unit (which includes Port Hope) published a report on cancer in the HKPR District [45]. The incidence of lung cancer (1986–2004) was increasing among women while remaining steady among men. This was also apparent in Ontario. Lung cancer incidence among both men and women was significantly greater in the HKPR District compared to Ontario. According to the report, higher lung cancer rates relative to Ontario were likely attributed to historically higher smoking rates among HKPR District residents. According to the 2006 Rapid Risk Factor Surveillance System (RRFSS) for HKPR District, 22.1% of the population were daily smokers [46]. The high lung cancer rates in Port Hope women are most likely due to historically higher smoking rates among residents. This may be the reason why lung cancer rates among women in Port Hope were less or not statistically significant when compared to population rates of similar socio-economic characteristics in Ontario and Canada, as demonstrated in tables 3 and 4, respectively.

Cancers of the stomach, liver, and urinary bladder are other smoking-related cancers identified as having sufficient evidence of being caused by smoking in the IARC monograph [43]. Port Hope residents did not have differences in cancer incidence rates for any of these cancers, although case numbers were small.

Environmental radiation exposure resulting from the nuclear industry within Port Hope is unlikely related to the elevated lung cancer incidence among women. The radon levels in Port Hope since 1993 have been less than 0.69 mSv yr^{-1} and are below Health Canada's radon guideline of 200 Bq m^{-3} [47], as a result of the remedial action carried out from 1971 to 1996. People living in Port Hope in the earlier period (1930s–1970s) were more likely to be exposed to elevated radon levels. Since lung cancer incidence was not elevated during the earlier time period (1971–1985) when radon exposures were more likely to be higher, the elevated lung cancer incidence is unlikely to be related to radon exposures. Even with a long latency period between exposure and disease outcome, there was ample time before the 1980s for elevated lung cancer incidence rates to emerge.

Lees *et al* [48] conducted a case-control study of lung cancer incidence and residential radiation exposures in Port Hope. However, the small number of lung cancer cases (cases = 27, controls = 49) in Port Hope from 1969 to 1979, together with the low levels of cumulative radiation exposure in the cases' homes, and the significant confounding of tobacco smoking (with 90% of the cases attributable to smoking) make it impossible to distinguish the role of radon gas in causing lung cancer in these Port Hope residents.

Lane *et al* [49] conducted a mortality (1950–1999) and cancer incidence (1969–1999) analysis of 2652 male Port Hope radium and uranium processing workers since 1932. Overall, all cancer incidence was similar to the general Canadian male population. Lung cancer was not statistically significantly associated with occupational radon exposures among Port Hope workers. The excess relative risk (ERR) for lung cancer mortality per 100 Working Level

Month[3] (WLM) was 0.18, 95% CI: −0.10, 1.49, $p = 0.59$, ($N = 101$ deaths, mean exposure 14.23 WLM). For lung cancer incidence, the ERR/100 WLM = 0.68, 95% CI: −0.23, 3.07, $p = 0.17$ ($N = 110$ cases, mean exposure 10.42 WLM) among Port Hope workers. No differences in risk were found between any other cancers or other causes of death and either radon or gamma exposures [49]. Since many Port Hope workers received both historic occupational and environmental radiation exposures (i.e., they lived in the area) the absence of an effect for lung cancer is noteworthy. None-the-less, without individual radon exposures or information on other known risk factors of lung cancer, especially tobacco smoking, it is difficult to interpret the elevated lung cancer incidence in Port Hope women.

The main strength of this study is that it is a relatively easy and inexpensive exploratory study to assess the relationship between living in Port Hope and cancer incidence compared to several reference groups. It focuses on the comparison of groups rather than individuals since individual-level data are either unavailable or impractical to gather [38]. Cancer reporting to the CCR is virtually complete and of high quality since it is routinely checked for accuracy through regular assessments by Statistics Canada and the cancer registries. The North American Association of Central Cancer Registries estimates that completeness of case ascertainment for Canadian provincial cancer registries is consistently in the 90%–95% range (www.naaccr.org/). Likewise, the Census of Canada undergoes vigorous quality and confidentiality procedures to assure the accuracy and privacy of census information (www12.statcan.gc.ca/censusrecensement/2011/). Incidence is preferred to mortality data since detailed clinical and demographic information is collected on individual cases and cancer sites with high survival rates may not be detected in mortality records. The comparison of Port Hope to health regions with similar socio-economic characteristics enhanced the comparability of results compared to the Ontario and Canadian populations and may have reduced confounding for social and economic determinants of health.

The major limitation of ecological analysis is the failure of ecological associations to reflect the biological effect at the individual level [38]. Thus, an association observed between variables on an aggregate level does not necessarily mean that the same association will exist at the individual level. Uniform exposures are assigned to the group whereas the exposures received by individuals vary and at the individual level are highly uncertain. Another major limitation is the lack of information on confounding risk factors (or effect modifiers) and this problem becomes more severe with increasing strength of the relationship between the confounding factor and the disease [38]. Since several cancer sites are associated with smoking, it has a substantial potential for bias in our study since this risk factor is not controlled. The lack of statistically significantly high incidence rates for cancers of the stomach, liver and bladder, which are tobacco-related cancer sites [43], suggests that smoking was not confounding this study. Confounding can also bias the outcome if confounders are distributed differently across groups. Unfortunately, these conditions cannot be checked with ecological data because those conditions are defined in terms of individual-level associations. This inability to check the validity of ecological results seriously limits biological inference. Lack of adequate data may also exist [38]. For example, malignant melanoma has been underreported in Quebec [40]. Therefore, Canada was not the best reference population for this cancer site. Likewise, cancers diagnosed outside Canada may be missed; however this underreporting is likely minimal. Temporal ambiguity may be an issue in our study since, despite the use of incidence data, it is unknown what the latent periods between individual's exposure and disease detection

[3] One Working Level Month is the exposure to radon decay products equivalent to one working month (170 h) at a concentration of one Working Level. One Working Level is that concentration of radon decay products in 1 l of air that will result in the ultimate release of 1.3×10^5 MeV of alpha particle energy.

were [38]. Finally, migration of individuals into or out of Port Hope can produce selection bias in a study [38]. Ontario is a major province to migrate from other provinces, although trend analysis of the last three decades reveals a mixed pattern of several years of gains followed by several years of losses. Unfortunately, information on intraprovincial migration, is only available at the census division level so we were unable to assess the migration pattern of Port Hope [50]. Little is known about the magnitude of this bias or how it can be reduced.

Multiple comparisons were made to assess cancer incidence by sex, peer group, and time period. There is considerable debate whether statistical adjustments are needed to adjust for possible spurious chance associations when multiple comparisons are made [51, 52]. We tried to limit the number of comparisons by focusing only on radiation-related cancers. We critically evaluated each association and looked for consistent patterns.

In conclusion, the cancer incidence rates of Port Hope residents have been analysed over the last 37 yr from 1971 to 2007. As in the previous study (1971–1996), the current study (1992–2007) showed no difference in childhood cancer incidence (age 0–14 yr) compared to the Ontario population. There was no statistically significant elevated leukaemia or other radiosensitive cancer incidence rates among those age 0–85+ yr, with the exception of statistically significant elevated lung cancer incidence among women. However, the statistical significance was reduced or disappeared when the comparison was made to populations with similar socio-economic characteristics. Overall, the cancer incidence in the local residents—for all cancers combined—was similar to the Ontario population, health regions of similar socio-economic characteristics in Ontario and in Canada, and the Canadian population. Although the current study covered an extended period of time (1992–2007), the power to detect risk at the sub-regional level of analysis was limited since the Port Hope population was small (16 500). The study nevertheless indicated that large differences in cancer incidence are not occurring in Port Hope compared to other similar communities and the general population.

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