Incidence of Cancer among Persons Living Near a Municipal Solid Waste Landfill Site in Montreal, Québec

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ABSTRACT. The Miron Quarry municipal solid waste landfill site in Montreal, Québec, generates copious quantities of methane and other gases, including a rich mixture of volatile organic compounds, some of which are recognized or suspected human carcinogens. The site is the third largest in North America and is located in the center of a densely populated area. Using data from the Québec Tumour Registry, we conducted Poisson regression analyses to evaluate whether cancer incidence among persons who lived near the site was higher than expected. Potential exposure to ambient air pollutants from the site was defined in terms of a set of geographic exposure zones proximal to the site. A set of reference areas distal from the site was selected to be similar to these exposure zones with respect to several key sociodemographic factors. Risk ratios (RRs) were adjusted for age and calendar year. Among men living in the exposure zone closest to the site, elevated risks were observed for cancers of the stomach (RR = 1.3, 95% confidence interval [95% CI] = 1.0–1.5); liver and intrahepatic bile ducts (RR = 1.3, 95% CI = 0.9–1.8); and trachea, bronchus, and lung (RR = 1.1, 95% CI = 1.0–1.2). Among women, rates of stomach cancer (RR = 1.2; 95% CI = 0.9–1.5) and cervix uteri cancer were elevated (RR = 1.2, 95% CI = 1.0–1.5), but breast cancer incidence was less than expected (RR = 0.9, 95% CI = 0.9–1.0). Prostate cancer was also elevated in one of the proximal exposure subzones (RR = 1.2, 95% CI = 1.0–1.4). Further studies at this and at other landfill sites are needed to confirm or refute these observations.

IN 1968, the Miron Quarry municipal solid waste (MSW) landfill site in Montreal, Québec, opened as a repository for domestic, commercial, and industrial wastes. At that time, little attention was given to the environmental and health consequences that might occur from the landfilling of refuse in an urban area. This may have been a serious oversight because there are about 100 000 persons who now live within 2 km of what is currently the third largest MSW landfill site in North America. The site has an area of about 750 000 m^2; a depth of 50–80 m; and, in January 1993, it was estimated that the site contained about 36 million tons of domestic, commercial, and industrial waste. Because the site is still in operation, it has not been capped.

The chief environmental problems are the amount of toxic chemicals on site, the production of liquids (leachates), and vapors and gases (biogas). Although leachates can contaminate underground water supplies, this is not a primary health concern because Montreal obtains its potable water from other sources. The main health considerations derive from the release of biogas into ambient air and soil. Other exposures include noise, diesel fumes, and dust.

Biogas is generated by anaerobic decomposition of organic compounds and by other processes.[1] It is a complex chemical mixture composed mainly of methane and carbon dioxide, but it also contains important quantities of volatile organic compounds and sulfur-based substances[1–5] (Table 1). Biogas is associated with pungent odors.

Since 1980, the biogas has been collected through a network of pipes, but the system has operated at low efficiency. After collection, the biogas is burned but combustion is incomplete. Information from other MSW landfill sites[6–9] suggests that the combustion products include nitrogen oxides, carbon dioxide, carbon monoxide, sulfur dioxide, and hydrochloric acid; it is also possible that dioxins, furans, and other volatile organic compounds are released.

Table 1.—Concentrations of Selected Constituents of the Biogas, as Measured in the Biogas Collection System of the Miron Quarry Municipal Solid Waste Landfill Site, Montreal, Quebec

Chemical	Range of concentration in biogas collection system*
Methane	~ 50%
Carbon dioxide	~ 50%
Hydrogen sulfide	Mean, 232 ppm
Mercaptans	Mean, 2 ppm
Hydrocarbons (C_5-C_{10})	114–1 061
Dichlorofluoromethane	47–218
Trichlorofluoromethane	6–141
Dichlorodifluoromethane	8–64
Toluene	1–154
Tetramethylbenzene isomers	35–87
M + P-xylene	24–64
O-xylene	12–24
3-Ethyl toluene	13–38
Ethyl benzene	2–36
Carbon disulfide	3–28
Chloroform	12-25
1,1-Dichloroethane	2–21
Methylene chloride	3–20
Acetone	5–17
Mesitylene	7–17
Tetrachloroethylene	6–17
1,1,1-Trichlorethane	1–16
Methyl ethyl ketone	1–16
1,4-Dichlorobenzene	7–14.8
Cumene	6–13
Trichloroethylene	1–9
Benzene	5–8
Vinyl chloride	1–7
Chlorobenzene	3–5
1,2-Dichloroethane	Detected†
Bromodichloromethane	Detected†
1,2-Dibromoethane	Detected†
Carbon tetrachloride	Detected†

Note: ppm = parts per million.
*Unless noted otherwise, values are mg/m³.
†Not quantified; data from reference 5.

Given the concerns for health expressed mainly by residents who live near the site, the city of Montreal commissioned the Public Health Department in 1991 to conduct a cancer-risk assessment study of the site. The justification for this study was that a number of volatile organic compounds found in the biogas were recognized or suspected human carcinogens. Concentrations of the constituents of the biogas, measured within the biogas capture system,[5] are shown in Table 1. Thirty-five volatile organic compounds were identified, including the recognized human carcinogens benzene and vinyl chloride monomer and the suspected human carcinogens methylene chloride, chloroform, 1,2-dichloroethane, bromodichloromethane, tetrachloroethylene, 1,4-dichlorobenzene, 1,2-dibromoethane, and carbon tetrachloride.[10,11]

There are minimal data that indicate the extent of exposure to biogas within the community, although residents who live up to about 1.5 km from the site have complained frequently of odors, and spot measurements of methane on streets of Montreal near the site resulted in concentrations that ranged from 0 to 25 ppm.[15] The presence of odors near MSW sites is not unusual.[1,12–14] Lateral migration of biogas through the ground is also a concern,[16,17] although we have no information regarding this potential route of exposure.

In addition to the ongoing cancer-risk assessment study, two epidemiologic studies have been completed and others are in progress. In one study, we found a 20% increase in the frequency of low birthweight (i.e., < 2 500 g) among children born to women who lived proximal to the site.[18] In the current study, we describe the second investigation,[19] the purpose of which was to determine if rates of cancer during the period 1981–1988 among persons who lived near the Miron Quarry MSW landfill site were higher than expected.

Material and Method

Definition of exposure zones. Given the lack of environmental exposure data, we carried out the analyses of cancer incidence rates according to a set of three areas proximal and distal to the quarry. These zones were formed by grouping contiguous or nearly contiguous three-character postal-code areas. These zones are hereafter referred to as the low-, medium-, and high-exposure zones (Fig. 1).

The high-exposure zone comprised the postal-code area in which the quarry is located and the postal-code areas that border it. This zone included an irregular region (about 28 km²), ranging from approximately 2–4 km distant from the edge of the site. The medium-exposure zone included all postal-code areas that bordered the high zone on the north, south, and east sides but excluded two postal-code areas in the east that were ≥ 4 km distant from the site. The low-exposure zone included all postal-code areas located northeast of the medium and high zones.

In addition, the high-exposure zone was divided into

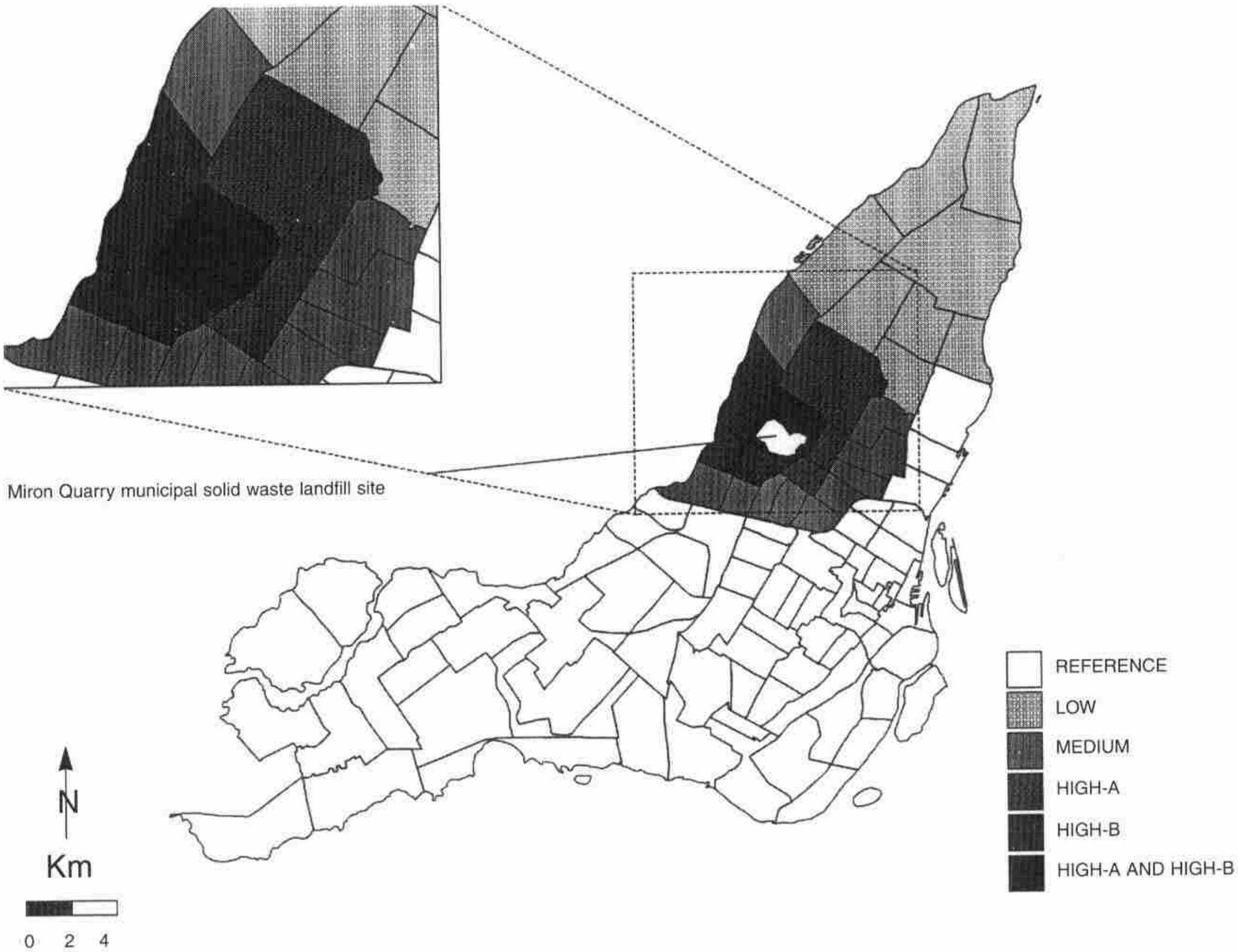

Fig. 1. Definition of the exposure zones surrounding the Miron Quarry municipal sold waste landfill site, Montreal, Québec.

two subzones (referred to as high-A and high-B; Fig. 1) so that prevailing winds could be accounted for. These two subzones were not mutually exclusive in that they both included the postal-code area in which the quarry is located.

Separate analyses were conducted for these four exposure zones, using four different referent zones, as follows:

Exposure zone	Reference zone
High, medium, low	Reference-1
High	Reference-2
High-A	Reference-3
High-B	Reference-4

The first reference zone (reference-1) comprised all "nonexposed" areas on the Island of Montreal. It was not entirely comparable sociodemographically to the three exposure zones (Table 2). For the three other exposure zones, we created separate reference zones from subsets of the unexposed areas of Montreal; therefore, these reference zones were similar to the high-exposure zones with respect to average household income, proportion of immigrants, and the proportion of persons whose native language was French. Similar proportions between exposure and reference zones for these factors, except for the proportion of French-speaking persons in the reference-3 zone, are shown in Table 2. As well, there were similar proportions of women and men; blacks; and persons who (a) rented their homes, (b) were below the poverty line, (c) were unemployed, (d) were < 4 and > 65 y of age, and (e) had not moved subsequent to the 1981 census. There were, however, differences in the proportion of persons with Italian ancestry, those with less than grade 9 education, and those having a university education.

Cancer incidence. Incident cases of cancer among persons who lived on the Island of Montreal at the time of diagnosis during the 8-y period from 1981 to 1988 were identified from the Québec Tumour Registry (Minister of Health and Social Affairs, Québec). The Registry relies solely on hospital discharge reports submitted by each hospital's medical records office. Since 1981, all Québec hospitals forwarded their discharge reports to a central collection and processing system known as Med-Echo.[20] Each hospital that reported to Med-Echo was responsible for the abstraction, coding, and verification of their own data; data verification was also carried out centrally, as was internal record linkage to distinguish prevalent from incident cases. The coding

Table 2.—Distribution of Selected Sociodemographic Characteristics of the Exposed and Reference Zones

Zone	Total population	Ratio of men to women (%)	Age (y) < 4 (%)	Age (y) ≥ 65 (%)	Characteristics: Renters (%)	Large households* (%)	French speaking (%)	Black persons (%)
Reference-1	1 059 270	91.8	5.4	12.7	68.0	2.1	52.3	1.9
Low	178 490	94.2	6.2	7.8	52.8	2.6	79.2	1.2
Medium	247 325	87.7	5.0	13.3	75.0	1.9	74.5	1.9
High	242 655	87.8	5.5	10.8	68.3	2.8	60.0	3.0
Reference-2	296 710	87.8	5.1	13.4	73.8	1.8	59.5	2.3
High	242 655	87.8	5.5	10.8	68.3	2.8	60.0	3.0
Reference-3	246 460	93.3	5.9	11.2	73.2	2.8	41.9	3.6
High-A	154 130	89.3	5.8	9.2	68.5	3.5	51.1	3.8
Reference-4	135 300	87.3	5.2	13.1	72.2	1.4	70.6	1.7
High-B	125 245	86.7	5.5	11.7	68.6	2.4	69.4	3.2

Zone	Italian descent (%)	Immigrants (%)	Nonmovers† (%)	Uneducated‡ (%)	University education (%)	Poverty rate§ (%)	Unemployment rate (%)	Average household income ($)
Reference-1	4.3	24.1	51.0	20.0	28.4	21.3	12.0	32 553
Low	11.1	11.2	49.0	24.0	13.8	16.7	10.1	33 499
Medium	9.6	16.2	51.1	28.9	15.6	25.1	13.0	24 941
High	25.5	24.1	55.2	30.3	13.3	22.3	11.1	27 841
Reference-2	6.1	22.4	51.1	22.4	21.3	22.0	12.0	28 150
High	25.5	24.1	55.2	30.3	13.3	22.3	11.1	27 841
Reference-3	10.8	33.3	47.4	22.9	25.0	25.9	13.9	27 594
High-A	32.2	29.2	57.1	32.9	11.2	23.9	11.4	27 651
Reference-4	6.1	14.3	54.0	25.3	17.2	22.0	12.3	27 359
High-B	17.2	19.3	53.2	28.9	14.1	23.5	11.3	27 190

Source: Statistics Canada, 1986 Census, Profiles A and B.
*Households with six or more persons.
†Persons 5 y of age and older who did not move between 1981 and 1986.
‡Persons 15 y and older who did not complete grade 9.
§Households under the poverty line in 1986.

of discharge diagnoses was not done by physicians but by trained nosologists at each hospital, using information on a summary sheet kept with the patient's chart. This summary sheet contained relevant diagnostic information recorded by the treating physicians. Information on sociodemographic factors was provided, usually by patients or by next-of-kin, and this information was recorded on the hospital discharge form.

The following information was used: date of birth; age at time of diagnosis; sex; three-character postal code of subject's residence at time of discharge; date of discharge (used as surrogate for date of diagnosis); and four-digit topological code, according to the ninth revision of the International Classification of Diseases (ICD9). The major sites of cancer, as well as a number of smaller a priori sites, were retained for the statistical analysis (Table 3).

Estimates of the population. Data from the Canadian censuses for 1981 and 1986 were used to estimate the size of the population, by sex and age, for each exposure and reference zone. With respect to the years 1981 and 1986, exact numbers provided by the census were used. For the intervening and following years, we conducted linear interpolation and extrapolation, respectively.

Statistical methods. Cancer cases were assigned to the exposure or reference zones, according to their postal code at time of discharge from hospital. For each site of cancer, we tabulated the number of incident cases, according to sex, 5-y age groups, calendar year, and residence in the exposure or reference zones. Rates in each zone were calculated by dividing the number of incident cases by the corresponding estimates of the population at risk.

It was assumed that incidence rates followed a Poisson distribution.[21] Multiplicative Poisson regression models that included age and calendar year as covariates were developed to estimate adjusted relative risks between exposed and reference zones. Poisson regression is a generalization of indirect standardization. It is a maximum likelihood procedure that can account for potential confounding factors and can allow the assessment of statistical interactions. We calculated 95% confidence intervals (95% CI), assuming that the log relative risks were distributed normally. Separate analyses were carried out for men and women. Statistical interactions between age and exposure zone and year and exposure zone were assessed with the likelihood ratio goodness-of-fit test, based on hierarchical models.[21,22] There were no significant statistical interactions between geographic region and age or calendar year for any site of cancer.

Results

Shown in Table 3 are the number of incident cases for the 17 sites of cancer among men and the 20 sites of cancer among women, according to exposure and reference zones for the entire Island of Montreal during the 8-y period 1981–1988. Of the 68 analyses conducted for men and the 80 analyses carried out for women, significant (95% CI excluding unity) or nearly significant positive associations (lower 95% confidence limit > 0.95) in the high-exposure zones were observed for two sites of cancer in women and four sites in men (Table 4). It should be noted that because the high-A and high-B exposures zones overlapped, the total number of cases in these two subzones was greater than the number in the high-exposure zone.

Rates of stomach cancer and cancer of the cervix uteri in women were in excess. Rates of breast cancer were, however, significantly less than expected. Among men, cancer of the stomach; cancer of the liver and intrahepatic bile ducts; cancer of the trachea, bronchus, and lung; and cancer of the prostate were higher than expected. Except for cancer of the liver and intrahepatic bile ducts, most excess relative risks for the high-exposure zones were quite low (i.e., < 1.3).

With respect to stomach cancer, relative risks between 1.04 and 1.27 were observed in the high-exposure zones. The pattern of risks was similar in men and women. In the high-exposure zone, there was little difference in relative risks between the reference area encompassing all other areas of Montreal (reference-1) and the "matched" reference zone for the high-exposure zone (reference-2). It was also observed that most of the excess risk was restricted to the high-A subzone, which was predominantly downwind from the site.

Analyses of cancer of the liver and intrahepatic bile ducts showed considerable differences between the sexes. These differences may have resulted from statistical variability, especially because there were few cases among women. For men, the relative risks in the high-exposure zone decreased from 1.55 when all of Montreal was used as a reference zone (reference-1) to 1.31 when a more sociodemographically comparable reference zone was used (reference-2). As was observed for stomach cancer, most of the excess risk was restricted to the high-A exposure zone (RR = 1.79, 95% CI = 1.21–2.64). The pattern of risks for women in the high-exposure subzones was directly opposite to that observed in men, although there was considerable variability in the estimates; the RR for the high-B exposure zone (RR = 1.54, 95% CI = 0.62–3.51) was higher than for the high-A zone (RR = 1.06).

There were no excess risks of lung cancer observed among women. For men, however, significantly high risks relative to the general population (reference-1) were observed in the low-, medium-, and high-exposure zones, with the lowest risks found in the high-exposure zone (RR = 1.11, 95% CI = 1.04–1.19). The RRs for the high-exposure zone were slightly lower when a matched reference zone (reference-2) was used (RR = 1.06, 95% CI = 0.98–1.16). Risks in the high-A zone were significantly different from unity (RR = 1.15, 95% CI = 1.04–1.29), and no excesses were detected in the high-B zone.

Table 3.—Number of Cases of Cancer, by Site, Sex, and Exposure and Reference Zones, Montreal, Quebec, 1981–1988

		Males (no.), by zone				Females (no.), by zone			
ICD-9*	Cancer site	Reference-1	Low	Medium	High	Reference-1	Low	Medium	High
151	Stomach	899	105	206	190	646	64	161	129
153	Colon	1 909	228	413	324	2 365	229	489	402
154	Rectum and rectosigmoid	1 262	154	296	221	1 080	115	208	203
155	Liver	265	34	59	72	129	15	35	25
156	Gallbladder	169	13	33	32	262	23	60	50
157	Pancreas	672	73	130	118	622	47	132	83
161	Larynx	665	80	150	137	126	26	32	26
162	Trachea, bronchus, and lung	5 158	685	1 264	1 008	2 096	237	458	330
163	Pleura	61	19	28	14	31	11	8	12
174	Female breast	1	0	0	0	6 226	669	1 231	1 060
180	Cervix uteri	0	0	0	0	751	81	196	171
182	Body of uterus	0	0	0	0	1 308	154	284	229
183	Ovary	0	0	0	0	1 012	104	208	173
185	Prostate	3 376	260	614	563	0	0	0	0
188	Kidney	1 793	177	360	290	717	65	127	98
189	Bladder	698	71	124	109	483	58	111	65
191	Brain	402	45	62	72	363	45	62	56
200	Lymphosarcoma and reticulum cell sarcoma	367	27	75	63	344	44	75	65
204	Lymphoid leukemia	384	44	71	69	291	29	63	52
205	Myeloid leukemia	247	23	46	31	208	19	42	37
208	Other leukemia of unspecified type	77	14	20	18	74	15	29	18

*Ninth revision of the International Classification of Diseases.

We did not observe an association between prostate cancer and living in the high-exposure zone. This null result, however, resulted from a significantly decreased risk in the high-A exposure zone (RR = 0.85, 95% CI = 0.73–0.98) and from a significantly elevated risk in the high-B exposure zone (RR = 1.18, 95% CI = 1.02–1.37).

Significantly elevated RRs of 30% and 23% were observed for cancer of the cervix uteri in the medium- and high-exposure zones, respectively. The RR for the high-exposure zone was not influenced by the choice of reference zone; however, risks for the two high-exposure subzones dropped dramatically and were non-significantly different from expected (RR = 1.07 and RR = 1.04 in the high-A and high-B zones, respectively).

Of all the sites of cancer considered, only female breast cancer showed a significant deficit in the high-exposure zone. The RRs for this exposure zone were invariant with respect to the reference zone used (RR = 0.92), but risks were lower in the high-A zone (RR = 0.88, 95% CI = 0.79–0.97) than in the high-B zone (RR = 0.95, 95% CI = 0.86–1.06).

Discussion

The results of this study suggest that there may be increased risks for cancers of the stomach, liver, lung, prostate, and cervix uteri among persons who live near the Miron Quarry MSW landfill site. Prior to considering these results in more detail, the relevant methodologic aspects of this study will be discussed.

A strength of this study was that a population-based cancer registry was used to identify incident cases. Residents of Québec treated out of province were not, however, included in the database unless they were hospitalized in Québec. Therefore, although there may have been some underreporting of cases, it is unlikely that this underreporting would be associated with area of residence because of Canada's universal health-care system and because of the similarity of the exposure and reference zones on sociodemographic factors, notably average income.

We are unaware of any studies in which the reliability of the data retained in the Cancer Registry's files has

Table 4.—Relative Risks for Selected Sites of Cancer, by Geographic Region and Sex

	Females			Males		
Geographic region	No.	RR	95% CI	No.	RR	95% CI
			Stomach			
Reference-1	646	1		899	1	
Low	64	1.05	0.81–1.36	105	1.13	0.92–1.38
Medium	161	1.20	1.01–1.43	206	1.15	0.99–1.34
High	129	1.14	0.95–1.38	190	1.24	1.06–1.44
Reference-2	158	1		208	1	
High	129	1.20	0.95–1.52	190	1.27	1.04–1.55
Reference-3	121	1		180	1	
High-A	76	1.25	0.94–1.67	121	1.20	0.95–1.51
Reference-4	72	1		107	1	
High-B	63	1.04	0.74–1.45	94	1.07	0.81–1.41
			Liver and intrahepatic bile ducts			
Reference-1	129	1		265	1	
Low	15	1.17	0.69–2.01	34	1.18	0.82–1.69
Medium	35	1.29	0.89–1.88	59	1.11	0.84–1.48
High	25	1.09	0.71–1.67	72	1.55	1.19–2.01
Reference-2	29	1		74	1	
High	25	1.23	0.72–2.09	72	1.31	0.95–1.81
Reference-3	23	1		50	1	
High-A	14	1.06	0.55–2.08	53	1.79	1.21–2.64
Reference-4	10	1		30	1	
High-B	13	1.54	0.62–3.51	30	1.20	0.77–1.99
			Trachea, bronchus, and lung			
Reference-1	2 096	1		5 158	1	
Low	237	1.07	0.94–1.23	685	1.23	1.14–1.34
Medium	458	1.02	0.92–1.13	1 264	1.22	1.15-1.30
High	330	0.86	0.76–0.96	1 008	1.11	1.04–1.19
Reference-2	522	1		1 293	1	
High	330	0.88	0.76–1.01	1 008	1.06	0.98–1.16
Reference-3	362	1		827	1	
High-A	193	0.90	0.75–1.07	562	1.15	1.04–1.29
Reference-4	255	1		684	1	
High-B	180	0.83	0.69–1.01	562	0.99	0.88–1.11

(continued on next page)

Table 4.—Continued

Geographic region	Females No.	Females RR	Females 95% CI	Males No.	Males RR	Males 95% CI
			Prostate			
Reference 1				3 376	1	
Low				260	0.80	0.70–0.90
Medium				614	0.92	0.84–1.00
High				563	1.01	0.90–1.11
Reference 2				820	1	
High				563	1.00	0.90–1.11
Reference-3				609	1	
High-A				259	0.85	0.73–0.98
Reference-4				366	1	
High-B				350	1.18	1.02–1.37
			Cervix uteri			
Reference-1	751	1				
Low	81	0.92	0.73–1.16			
Medium	196	1.30	1.11–1.52			
High	171	1.23	1.04–1.45			
Reference-2	185	1				
High	171	1.21	0.98–1.49			
Reference-3	156	1				
High-A	104	1.07	0.83–1.37			
Reference-4	98	1				
High-B	88	1.04	0.78–1.38			
			Female breast			
Reference-1	6 226	1				
Low	669	0.98	0.91–1.07			
Medium	1 231	0.94	0.89–1.07			
High	1 060	0.92	0.86–0.98			
Reference-2	1 567	1				
High	1 060	0.92	0.85–0.99			
Reference-3	1 064	1				
High-A	561	0.88	0.79–0.97			
Reference-4	736	1				
High-B	605	0.95	0.86–1.06			

Notes: No. = number of cases, RR = relative risk, and CI = confidence interval.

been investigated. Errors can occur during the coding of diagnoses because of incorrect interpretations of the diagnostic summary form retained in the hospital chart or in the transcription of information onto computer files. A recently completed reliability study of respiratory and other diseases, based on discharges from hospitals (Med-Echo system) in Montreal from which the Tumour Registry derives its data, has shown that diagnosis, age, sex, year of admission, municipality codes, and postal codes were recorded quite accurately.[27] Indirect evidence regarding the accuracy of the diagnoses for those sites of cancer presented here is provided by the similarity between Montreal and other jurisdictions of age- specific incidence rates[28] and the ratio of male-to-female cancer cases.[29,30] It is, therefore, likely that the data from the Tumour Registry are sufficiently accurate for the purposes of the analyses presented here and that they are superior to data retained in mortality records, for which the accuracy of diagnosing cancer has been estimated at about 80%.[31,32]

The main limitations of this study were related to potential errors in exposure classification, to inadequate control of potential confounding factors, and to a relatively short period from first exposure (1968) to cancer onset (1981–1988).

Because no direct measurements of biogas were available, we defined exposure zones in terms of proximity to the site. This probably led to misclassification because it was likely that there was heterogeneity in actual exposures to biogas in these broad areas. In an attempt to distinguish between "downwind" and "upwind" areas, the exposure zone closest to the site was divided into two subzones. Our results for stomach cancer in men and women and for liver cancer and lung cancer in men were consistent with the assumption that these subzones represented different average exposure levels, although results for prostate cancer did not.

Because exposure data were unavailable, we were unable to directly assess cancer incidence in relation to exposure to biogas.

Other than age and sex, potential confounding factors could not be controlled directly in the statistical analyses. Indirect control over a number of key sociodemographic factors was, however, achieved through the matching of exposure and reference areas. Because the exposure zones were fairly broad, we could not match as closely as we would have liked (e.g., the high-exposure zone was different from the reference-2 zone with respect to percentages of Italian-speaking persons and in level of education). This difference in the proportion of persons of Italian extraction may have had a bearing on the results for stomach cancer. A study by Terracini et al.[33] showed a statistically significant increased risk of stomach cancer among Montreal males of Italian origin. However, adjustment for socioeconomic status and urban residence in childhood reduced the differences considerably. It was not possible, however, to evaluate formally the magnitude of these potentially distorting effects.

One of the analyses dealt with the comparison of cancer incidence rates for the high-, medium-, and low-exposure zones with respect to the remaining areas of Montreal. These comparisons should not be interpreted as being representative of exposure- or distance-response relationships because it is unknown to what extent, if any, biogas migrated into the medium- and low-exposure zones. It is nonetheless difficult to interpret the results for stomach cancer in men and women and lung cancer in men because they showed excess risks in the low- and medium-exposure zones, as well as in the high-exposure zone. For lung cancer, the excess risks may have been caused, for example, by a greater frequency of cigarette consumption or, for the low- and medium-exposure zones, by emissions from petroleum and petrochemical plants located in the east end of Montreal. Results from previous environmental studies near petrochemical plants have not, however, been consistent in indicating excess risks for lung cancer.[23–25]

No data were available regarding residential history; therefore, it was not possible to determine the length of time that subjects had lived in the relevant geographic areas. Given that the site has been in operation since 1968 and the cancer data cover the period 1981–1988, latency and exposure periods overlapped. Moreover, the maximum latency period was only 20 y, which, for solid tumors, is quite short.[26]

Some or all of the positive findings may have arisen because of multiple testing. Including all four exposure zones, 80 and 68 tests were carried out for women and men, respectively. Because these tests were not independent, it is difficult to predict the number of associations that would be expected solely by chance. Focusing on the analyses of the high-exposure zone, using only the reference-2 zone and assuming a 5% level of statistical significance, one would have expected to detect about one significant association for men and one for women. We observed one excess positive association among women and one among men.

The large difference in rates between men and women for liver cancer is consistent with that observed usually; women tend to have a higher incidence of gallbladder cancer and a lower incidence of liver cancer than men.[29,30] The increased risk in liver cancer among men is intriguing given that vinyl chloride monomer—a recognized liver carcinogen[10,11]—is present in the biogas. However, the excess risks may have resulted from other risk factors (e.g., alcohol consumption, aflatoxin exposure, and hepatitis-B virus). Risks among women were also greater than unity, but there was considerable variability in the estimates.

It would be useful to compare our estimates of RR with those obtained from calculating the expected number of excess cancers attributable to exposures to specific agents, using, for example, lifetable methods and available dose-response coefficients[34] (e.g., IRIS slopes[11]). This is the subject of our risk-assessment study mentioned above, which will be completed when environmental measurements have been carried out.

Conclusion

This is the first study in which cancer incidence was assessed in a population living near an active MSW landfill site. Because of the unavailability of detailed environmental data to define exposure areas and the absence of some important potentially confounding variables, we cannot conclude whether the excess risks for cancer observed here represent true associations with exposure to biogas. The results from this investigation will, however, be used in conjunction with other studies that will be carried out at the site.

Additional studies are warranted. There are approximately 6 000 MSW landfill sites currently in operation in the United States,[4] and, given that since World War II almost all communities in North America have used this method of solid waste disposal,[35] there must be an enormous number of inactive sites. Although MSW landfill sites were usually situated outside of urban areas, many sites are now in close proximity to large populations. The potential toxicity of emissions from MSW landfill sites is underscored by the fact that many are classified as hazardous; by 1986, 187 of the 850 sites proposed for the American superfund priority list for remedial action were of this type.[36]

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A preliminary version of this study was presented at the Third National Conference of the Canadian Society for Epidemiology and Biostatistics, Québec, Québec, June 2–4, 1993.

Submitted for publication May 16, 1994; revised; accepted for publication December 15, 1994.

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