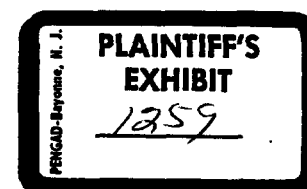


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Cancer Mortality in Oil Refinery Workers

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Crude petroleum, its fractions and the polycyclic aromatic hydrocarbons produced in the refining process have all been shown to cause cancer in laboratory animals, most commonly in the liver, lung and kidney.^{1,2}

Studies of humans exposed to petroleum or its fractions have demonstrated increased risks of cancers of the skin, scrotum and lung, and less frequently, the gastrointestinal tract and bladder.^{3,7}

In spite of the evidence suggesting that workers in the oil refining industry might experience an increased risk of cancer, few studies of cancer risks among these workers have been made until recently. In a study of workers in 17 oil refineries in the United States, Gaffey et al.⁸ found that the ratio of observed to expected cancer deaths was greatest in workers with the lowest exposure to hydrocarbons. The risk of death from cancer of the digestive system decreased with increasing exposure to hydrocarbons, whereas death from respiratory and genital cancers increased with such exposure. On the other hand, the results of a study conducted by the medical director of Imperial Oil Limited suggested that refinery employees had increased death rates from cancers of the intestine (ICDA 152-153) and other digestive organs (ICDA 155-159).

The present study was designed to test the following hypotheses: (1) Workers exposed to petroleum and its products have an increased risk of mortality from cancer, especially of the intestines (including rectum) and other digestive organs, than do nonexposed workers. Reference to the intestines throughout this article will assume the inclusion of the rectum (ICDA codes 152-154). (2) Workers on a refinery site have a similarly increased risk of cancer

mortality, compared with nonrefinery workers. The second hypothesis was intended as a rather crude assessment of the presence-on-a-refinery-site of carcinogens other than those present in petroleum and its products.

Materials and Methods

The Data. — Imperial Oil Limited provided the following information for 21,732 male employees, who were either active in the company, or were company annuitants (both full annuitants and deferred annuitants, i.e., persons no longer with the company after 10-15 years service, but members of the pension scheme) during the period 1964 to 1973, inclusive: (1) current age; (2) years of service with the company; (3) status (active, retired, terminated, dead); (4) date of retirement; (5) date of death; (6) cause of death; (7) job title (e.g., chemist, warehouseman); and, (8) job function and location (kind of activity, e.g., producing, chemical plant, and its location by province and refinery or non-refinery site).

This information regarding job title, location and function was sufficient to categorize employees by exposure and refinery work, according to the following definitions.

1. Exposure was defined as daily occupational contact with petroleum or its products; moderate exposure as contact less than daily (e.g., it could represent as much as two weeks every month); and nonexposure as no known occupational contact. On the advice of the company's industrial hygienist, the department, site, job titles and functions were used to place employees in one of the three exposure categories. A small group of employees (1.6% of the total) was exposed for only part of the 10-year period. Since the group was small, those members working at least half of the 10-year period in exposed jobs were designated exposed, and those working less than half, nonexposed.

2. Refinery work was defined as daily work on a refinery site, irrespective of exposure to petroleum. Information provided regarding location of work permitted the classification of employees as refinery or non-refinery workers.

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Study done by Exxon

Definition of the Study Population

Following the categorization of employees, the final study population was defined by making the following exclusions from the total population: (1) females, because the number was very small; (2) summer students, because the number was small and the total exposure time for each student short; (3) short-term employees who terminated during the study period, with less than five years service with the company, because it was not practicable to trace these employees; (4) employees active with the company in the final year of the study, but who had had less than one full year of employment; (5) 19 retired employees who died early in the study period, but for whom no information could be found with which to categorize their exposure or place of work. Among the excluded short-term employees and the 19 annuitants, only two cancer deaths were known to have occurred.

Fig 1 details the final study population of 15,032 male employees, who had been observed either as active employees or annuitants for all or part of the 10-year observation period

A total of 865 employees were lost to follow-up. This group was not part of the 6,681 short-term employees excluded from the study population, but was made up of persons with 5 to 15 years service who left the company and with whom no contact was maintained by the company because they were not members of the pension scheme. These untraced employees were distributed as follows in the refinery/exposure comparison groups and their controls: exposed, 4.9%; moderately exposed, 5.9%; nonexposed, 7.4%; refinery, 2.2% and non-refinery, 7.9%.

Verification of Cause of Death

The Provincial Registrars, in all but one province, and Statistics Canada assisted the company medical director by providing, from the death certificates, verification of the underlying cause of death. Death certification information on underlying cause was not located for 1.6% of the 1,511 deaths which occurred during the period of observation. Analyses in this study are based upon those deaths citing cancer as the underlying cause on the death certificate.

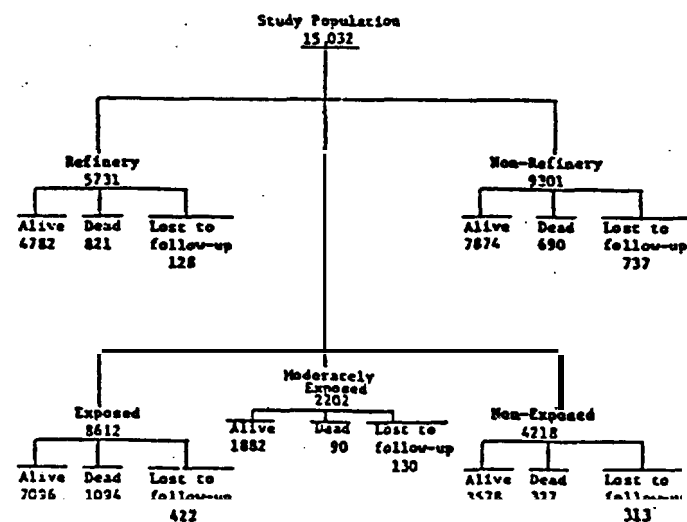


Fig 1. — Study population. Imperial Oil Limited. 1964-1973.

Analysis of the Data

Since employees were observed for varying lengths of time during the 10-year observation period, person-years at risk were used as the denominators for mortality rates. Both active employees and annuitants contributed to the person-years at risk.

Age-adjusted cause-specific mortality rates formed the basis for comparisons of the exposed and nonexposed and the refinery and non-refinery groups. The direct method of age adjustment was used throughout, with the total study population as the standard. Tests of significance have been made by a chi square test of the discrepancy between the distribution of the observed number, of deaths in each exposure category and the number expected, assuming that the number of deaths in each category is proportional to the distribution of person-years in each category. This procedure was used in preference to direct significance tests of differences between age-adjusted rates, since the latter tests have not been adapted for use where the denominators of the rates are person-years at risk.

For examination of mortality rates by duration of employment, person-years in each duration category were determined by allocating the person-years contributed by each employee during the 10-year period, to the appropriate age and duration category.¹⁶ For example, an employee entering the company in 1940 at age 20 would be age 44 in 1964, the beginning year of observation, and would have had 24 years of employment. The first five years of the 10-year observation period would be allocated to the appropriate age group in the less than 30-year duration group. The remaining five years, from age 49 onwards, would be allocated by age to the 30 and over duration group.

Results

In the study population during the 10-year observation period there were 1,511 deaths of which 301 were due to cancer. Table 1 shows the percentage distribution of deaths by major cause. Disease of the circulatory system and malignant neoplasms together account for nearly 80% of all deaths. An analysis of deaths from causes other than cancer will be the subject of a separate paper. An examination of the distribution of deaths by cause and age revealed that only five cancer deaths occurred in employees under the age of 40. Consequently, the under 40 age group was excluded from subsequent mortality comparisons. The distributions of person-years at risk by age contributed by employees age 40 and over in the

Table 1. — Percentage Distribution of Deaths in the Study Population by Major Cause. 1964-1973.

Cause of Death*	No.	%
Malignant neoplasms (140-209)	301	19.9
Diseases of circulatory system (390-458)	905	59.9
Diseases of respiratory system (460-519)	90	6.0
Diseases of digestive system (520-577)	51	3.4
Accidents, poisonings and violence (800-999)	59	3.9
All other	105	6.9
Total	1,511	100.0

*ICDA Codes, 8th Revision (1965) shown in parentheses

Table 2. — Person-Years at Risk by Age for the Study Population, 1964-1973.*

Age	Total	Nonexposed	Moderately Goosed	Exposed	Non-Refinery	Refinery
40-44	16,750.5	4,661.0	2,980.0	9,109.5	10,961.0	5,789.5
45-49	15,114.0	3,932.5	2,396.0	8,785.5	9,258.5	5,855.5
50-54	12,661.5	3,321.5	1,606.5	7,733.5	7,354.5	5,307.0
55-59	10,793.0	2,944.5	1,209.5	6,639.0	6,005.0	4,788.0
60-64	9,065.0	2,349.0	830.0	5,886.0	4,741.0	4,324.0
65-69	7,110.5	1,718.5	456.0	4,936.0	3,445.5	3,665.0
70-74	5,074.0	1,143.5	352.0	3,578.5	2,326.0	2,748.0
75-79	3,178.5	1,111.5	292.5	2,220.0	1,404.0	1,774.5
80-84	1,667.5	342.5	152.5	1,172.5	686.0	981.5
85+	642.5	133.5	34.5	474.5	271.0	371.5
Total	82,057.0	21,212.5	10,309.5	50,535.0	46,452.5	35,604.5

*Age groups less than 40 excluded from this table

refinery and exposed groups and their corresponding control groups are shown in Table 2

Comparison of Cancer Mortality in the Exposed and Refinery Groups and Their Controls

Before cancer mortality was examined, the comparability of the exposed and refinery groups and their respective controls was assessed for the following variables: year of first observation in the study, age at last observation, and geographic location. A high percentage of both study groups and their controls entered the study in 1964, the first year of observation. Over 70% of the exposed, moderately exposed and nonexposed groups and about 80% of the refinery and nonrefinery groups entered in 1964. In all groups, small percentages entered observation in each subsequent year. Thus, the vast majority of each study group was employed with the company in 1964, the beginning of the observation period.

The geographic comparison revealed that the distribution of the exposed/moderately exposed/nonexposed groups by province was as follows: about 10% (exposed) vs. 5% (moderately exposed) vs. 6% (nonexposed) in the Atlantic provinces; 50% (exposed) vs. 46% (moderately exposed) vs. 60% (nonexposed) in Ontario and Quebec; and, in the western provinces, 33% (exposed) vs. 48% (moderately exposed) vs. 34% (nonexposed). The refin-

ery/non-refinery groups were not as consistently comparable geographically. Ten percent of the refinery group compared with 7% of the nonrefinery group were in the Atlantic provinces; the refinery/non-refinery comparisons in Ontario and Quebec and in the western provinces were 60%:47% and 27%:40%, respectively. The remainders were in scattered sites. These obvious differences dictated the need to consider the geographic variable in examining any differences in disease rates among subgroups. Since there were few deaths in the scattered geographic sites this group was omitted from these analyses.

The age distributions of workers over the age of 40 in the exposed and refinery groups and their respective controls were compared. Both comparisons revealed age discrepancies, with the exposed and refinery groups being older than their respective controls. Thirty-three percent of the exposed vs. 16% of the moderately exposed vs. 25% of the nonexposed and 37% of the refinery vs. 23% of the non-refinery were 65 years old or more.

The exposure and refinery study groups and their controls were not examined for comparability with respect to other variables, such as year of birth and year beginning employment, because these variables were highly correlated with age at last observation. No information was available, such as income or education, to examine carefully the comparability of the study groups and their con-

Table 3. — Percentage Distribution of Cancer Deaths in the Exposure and Refinery Comparison Groups, 1964-1973.*

Site of Cancer†	Cancer Deaths				
	Nonexposed (N=65)	Moderately Exposed (N=16)	Exposed (N=215)	Non-Refinery (N=132)	Refinery (N=164)
Buccal cavity and pharynx (140-149)	1.5%	—	2.8%	2.3%	24%
Esophagus and stomach (150, 151)	4.6	12.5%	13.0	11.4	11.0
Large intestine and rectum (153, 154)	18.5	6.2	13.5	10.6	17.1
Other digestive organs (155-159)	12.3	31.2	9.3	9.1	12.8
Trachea, bronchus, lung (162)	20.0	12.5	31.2	29.5	26.2
Other respiratory organs (160, 161, 163)	1.5	—	1.4	1.5	1.2
Bone, connective tissue, skin (170-174)	7.7	6.2	2.3	5.3	2.4
Prostate (185)	10.8	—	8.4	7.6	9.1
Urinary organs (188, 189)	7.7	—	6.5	6.8	6.1
Other and unspecified sites (190-199)	7.7	6.2	5.6	4.5	7.3
Lymphatic and hematopoietic system (200-209)	7.7	25.0	6.0	11.4	4.3
Total	100.0	99.8	100.0	100.0	99.9

*Age groups less than 40 excluded from this table.

†ICDA Codes, 6th Revision (1955) shown in brackets.

Table 4. — Age-Adjusted^a Cancer Mortality Rates for Specific Sites in Exposed and Nonexposed Workers, 1964-1973.^b

Site of Cancer ^c	Age-Adjusted Mortality Rate per 10,000 Person-Years				
	Nonexposed Rate	Moderately Exposed Rate	Relative Risk	Exposed Rate	Relative Risk
All sites (140-209)	32.3 (65) ^d	18.4 (16)	0.57	39.7 (215)	1.23 ^e
Esophagus and stomach (150,151)	1.6 (3)	1.7 (2)	1.06	5.2 (28)	3.25 ^e
Intestines and rectum (153,154)	6.1 (12)	1.5 (1)	0.26	5.3 (29)	0.88
Other digestive organs (155-159)	3.9 (8)	2.6 (5)	0.67	3.5 (20)	0.90
Trachea, bronchus, lung (162)	6.6 (13)	2.6 (2)	0.39	12.5 (67)	1.89 ^e
Prostate (185)	3.8 (7)	—	—	3.2 (18)	0.84
Urinary bladder, kidney (186,189)	2.4 (5)	—	—	2.6 (14)	1.08
Lymphatic hematopoietic system (200,209)	2.6 (7)	4.9 (4)	1.88	2.3 (13)	0.88

^aDirect adjustment using the study population as standard^bAge groups less than 40 excluded from this table^cICDA codes, 8th Revision (1965) shown in brackets^dIndicates that the exposed rates differed significantly from the nonexposed at $p < 0.05$, chi square, d.f. = 1^(*)^eNumbers of deaths upon which rates are based shown in parentheses

trols for social class. Nor was any information available on personal habits, such as tobacco and alcohol use.

The distribution of cancer deaths at ages 40 and over in the exposure and refinery groups and their controls is shown in Table 3. In all groups the sites accounting for the largest percentages of deaths were trachea, bronchus and lung, and the digestive tract, particularly the intestines in the exposed and nonexposed and other digestive system organs in the moderately exposed workers. There were no cancers of the small intestines. Hence, all further mention of intestines will assume the large intestines (ICDA 153) and rectum (ICDA 154).

Table 4 shows the age-adjusted cancer mortality rates for the major sites in the exposed and nonexposed groups and the ratios of the exposed:nonexposed and the moderately exposed:nonexposed. Mortality from all malignant neoplasms in the exposed group was significantly above that in the nonexposed. The two sites for which mortality was significantly higher and which accounted for the largest part of the excess cancer mortality in the exposed group were esophagus and stomach, and

trachea, bronchus and lung. The risk of death from cancer of the esophagus and stomach in the exposed group was 3¼ times that in the nonexposed — for lung cancer, the risk in the exposed group was almost twice that in the nonexposed. The risks in the moderately exposed group were lower than the nonexposed. The numbers of deaths in the moderately exposed group were small; hence, all further exposure comparisons excluded the moderately exposed group.

The pattern of increased risk of death from cancers of the esophagus and stomach, and trachea, bronchus and lung in the exposed group persisted when geographic factors were considered. Table 5 shows these comparisons. Although none of the exposed/nonexposed differences were statistically significant, it is noteworthy that the relative risk of esophageal and stomach cancer was elevated among exposed workers in Ontario and Quebec and to a lesser degree in the western provinces. The risk of lung cancer seemed to increase geometrically from eastern to western Canada.

Table 6 shows the age-adjusted stomach and lung can-

Table 5. — Age-Adjusted^a Stomach and Lung Cancer Mortality Rates in Exposed and Nonexposed Workers by Geographic Location, 1964-1973.^b

Geographic Location ^c	Cancer Mortality/10,000 Person-Years					
	Esophagus and Stomach			Trachea, Bronchus and Lung		
	Exposed	Nonexposed	Relative Risk	Exposed	Nonexposed	Relative Risk
Atlantic provinces	11.9 (1) ^d	—	—	13.8 (8)	19.7 (2)	0.7
Ontario/Quebec	46 (14)	0.8 (1)	5.8	11.6 (34)	7.3 (9)	1.6
Western provinces	73 (11)	4 (2)	1.8	14.0 (21)	3.5 (2)	4.0

Table 6. — Age-Adjusted* Stomach and Lung Cancer Mortality Rates in Exposed Workers by Duration of Employment, 1964-1973.†		
Duration of Employment (Years)	Cancer Mortality Rates/10,000 Person-Years (Exposed Workers)	
	Esophagus and Stomach	Trachea, Bronchus and Lung
11-20	3.0 (4)‡	10.1 (11)
21-30	5.8 (11)	14.7 (27)
31+	7.8 (13)	19.6 (29)

*Direct adjustment with the study population, age ≥ 40 , > 10 years service as the standard

†Age groups less than 40 excluded from this table

‡Numbers of deaths upon which rates are based are shown in parentheses

cancer mortality rates in the exposed workers by duration of employment, where duration of employment was the only available means of estimating the dose of petroleum or its products accumulated over time. It should be noted that there were no cancer deaths for these causes among workers with 10 or less years of employment. Clearly both esophagus and stomach, and trachea, bronchus and lung cancer mortality rates increased with increasing duration of employment.

The foregoing analysis of cancer mortality by major site was repeated for the refinery and non-refinery groups. Table 7 shows the site-specific age-adjusted rates in the two groups, and the relative risks. As with the exposed/non-exposed comparison, there was a significantly increased risk of all malignant neoplasms in the refinery group. The sites which here accounted for the largest part of the excess were intestines and other digestive organs, the risks for refinery workers being almost twice as great as those for non-refinery workers. The mortality in the refinery group from neoplasms of the lymphatic and hematopoietic systems was about half that in the non-refinery group.

The excess of intestinal and other digestive system cancers in the refinery group was examined specifically for geographic location and for duration of employment. Table 8 shows the geographic analysis. The increased risks of mortality from intestinal cancer, and from intes-

Site of Cancer‡	Age-Adjusted Mortality Rates/10,000 Person-Years		
	Refinery	Non-Refinery	Relative Risk
All sites (140-209)	40.6 (164)†	31.4 (132)	1.29§
Esophagus and stomach (150, 151)	4.5 (18)	3.7 (15)	1.22
Intestines & rectum (153, 154)	6.9 (28)	3.5 (14)	1.97§
Other digestive organs (155-159)	5.1 (21)	2.8 (12)	1.82
Trachea, bronchus, lung (162)	10.9 (43)	9.2 (39)	1.18
Prostate (165)	33 (15)	2.6 (10)	1.27
Urinary bladder, kidney (188, 189)	2.5 (10)	2.1 (15)	1.19
Lymphatic and hematopoietic system (200-209)	1.7 (7)	3.9 (15)	0.46

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7. age-specific mortality rates for both sites were compared. NO consistent age-specific differences between the refinery group and its control were seen for either site. Stomach and lung cancer mortality in the refinery and non-refinery groups were not explored further.

Table 8. — Age-Adjusted* Intestinal and Other Digestive Organ Cancer Mortality in Refinery and Non-Refinery Workers by Geographic Location, 1964-1973.†						
Geographic Location	Cancer Mortality Rates/10,000 Person-Years					
	Refinery	Intestines Non-Refinery	Relative Risk‡	Refinery	Intestines and Other Digestive Organs Non-Refinery	Relative Risk‡
Atlantic provinces	—	—	—	10.9 (4)§	5.0 (2)	2.2
Ontario/Quebec	8.8 (22)	5.8 (12)	1.5	14.7 (37)	9.7 (20)	1.5
Western provinces	6.7 (4)	1.5 (2)	4.5	7.9 (2)	2.9 (4)	2.7

*Direct adjustment using the study population as standard

†Ages ≥ 40

‡No refinery rate differed significantly from the corresponding non-refinery rate

§Numbers of deaths upon which rates are based are shown in parentheses

Table 9. — Age-Adjusted* Intestinal, Other Digestive Organ, Stomach and Lung Cancer Mortality Rates in Refinery/Exposure Subgroups, 1964-1973.†

Subgroup	Age-Adjusted Cancer Mortality Rates/10,000 Person-Years			
	Intestines (153, 154)‡	Other Digestive Organs (155-159)	Esophagus and Stomach (150, 151)	Trachea, Bronchus, and Lung (162)
Refinery exposed	7.2 (26)§	4.4 (17)	4.7 (17)	11.9 (42)
Refinery moderately exposed	8.8 (1)	6.7 (2)	3.3 (1)	—
Refinery nonexposed	5.5 (1)	9.3 (2)	—	—
Non-refinery exposed	1.7 (3)	1.9 (3)	6.0 (11)	13.6 (25)
Non-refinery moderately exposed	—	15.2 (3)	5.1 (1)	7.2 (2)
Non-refinery nonexposed	6.4 (11)	3.2 (6)	1.9 (3)	6.9 (13)

*Direct adjustment using the study population as standard

†Age groups less than 40 excluded from this table

‡ICDA codes, 8th Revision (1965) shown in brackets

§Numbers of deaths upon which rates are based shown in parentheses

Mortality Rates in Specific Subgroups of the Employee Population

Age-adjusted mortality rates for intestinal and other digestive organ cancers and esophageal and stomach, and trachea, bronchus and lung cancer, the sites which were elevated in the refinery and exposed groups, respectively, are shown in Table 9 in subgroups of the refinery exposure categories. The slightly elevated stomach and lung cancer mortality in the exposed and moderately exposed groups relative to the nonexposed groups supported the earlier evidence that increased risks of stomach and lung cancer occurred in workers exposed to crude petroleum and its products, and suggested that the increased risks were independent of place of exposure. The pattern of intestinal and other digestive organ cancer risk by exposure/refinery subgroup is less clear. If workers at a refinery site were exposed to a carcinogen other than petroleum, one would expect the rates for the refinery subgroups to be greater than the rates for nonrefinery groups, but there was no such consistent pattern. However, the rates were based upon very small numbers of deaths.

Table 10 shows the age-adjusted cancer mortality rates by job titles for the following sites: intestines, other digestive system organs, esophagus and stomach, and trachea, bronchus and lung. The ratios of the job-specific mortality rates to the study population rate are included.

Table 10. — Age-Adjusted* Cancer Mortality Rates by Site and by Specific Job, 1964-1973.†

Job Title‡	Age-Adjusted Cancer Mortality Rates/10,000 Person-Years							
	Intestines (153,154)		Other Digestive Organs (155-159)		Esophagus and Stomach (150,151)		Trachea, Bronchus and Lung (162)	
	Rate	Risk Ratio§	Rate	Risk Ratio	Rate	Risk Ratio	Rate	Risk Ratio
Services; laundry, custodial, watchmen, inspectors (N=156) (RE)	11.91 (3)	2.3	—	—	11.9 (3)	3.0	—	—
Mechanics, boiler-makers, pipe fitters (N=1496) (E)	9.8 (13)	1.9	5.4 (8)	1.4	4.0 (5)	1.0	12.7 (17)	1.3
Operations, processing, field supervisors, dewaxing, asphalt stills, crude stills, clay press (N=1303) (RE)	6.7 (7)	1.3	4.5 (5)	1.1	4.8 (5)	1.2	9.1 (10)	0.9
Office workers (including executives) (N=2546) (NE)	6.1 (11)	1.2	2.6 (5)	.6	—	—	22.5 (12)	2.2
Garage workers, route salesmen (N=807) (NR, E)	4.2 (2)	.8	3.5 (2)	.9	9.0 (4)	2.2	12.0 (7)	1.2
Plant clerks (N=609) (ME, E)	3.6 (2)	.7	—	—	—	—	17.9 (9)	1.8
Utilities, building trades, boilerhouse (N=226) (RE)	3.4 (2)	.7	—	—	5.3 (2)	1.3	22.3 (5)	2.2
Engineers (N=625) (ME)	—	—	9.2 (4)	2.3	3.7 (2)	0.9	—	—
Packaging, shipping (N=494) (E)	—	—	—	—	4.4 (2)	1.1	10.6 (5)	1.1
Study population	5.1 (42)	1.0	4.0 (33)	1.0	4.0 (33)	1.0	10.0 (82)	1.0

*Direct adjustment using the study population as standard

†Age groups less than 40 excluded from this table

‡Refinery and exposure groups are shown in parentheses: R=refinery, NR=Non-refinery, E=exposed, ME=moderately exposed, NE=nonexposed

§Ratio of rate in subgroup to study population rate

¶Numbers of deaths upon which rates are based are shown in parentheses

Rates have been calculated only for job categories containing at least two deaths. Some job categories overlapped refinery and exposure groups, and refinery and exposure groups are identified for each job title. Because the job grouping used for this analysis did not arise from a priori hypotheses, but from an examination of the job distribution of the deaths, no tests of significance have been made. Although most of these rates were based upon very small numbers, some of these observations merit further exploration. Rates for the specific cancers which were about twice as high in particular groups of jobs as in the study population, occurred as follows: (1) intestinal cancer, in service workers (laundry workers, custodians, watchmen and inspectors), mechanics, boilermakers and pipefitters; (2) other digestive organ cancers in engineers; (3) stomach cancer in service workers, garage workers and route salesmen; and, (4) lung cancer in office workers, workers in utilities, building trades and boilermakers.

The intestinal cancer death rates by job and refinery/exposure subgroup did not follow any pattern, since the highest rates occurred in workers exposed on a refinery site (service workers) and in workers classified as exposed, some at a refinery site and others not necessarily at a refinery site (e.g., mechanics). Stomach cancer mortality by job was consistently highest in workers in jobs categorized as exposed (service workers and garage workers). Lung cancer mortality was high in a group of exposed workers (utilities, building trades, boilerhouse) and most noticeably in nonexposed office workers. Since the latter group included executives, it is possible that workers previously in exposed jobs have been moved later in life to executive positions or less physically taxing office jobs.

Discussion

Comparison of workers exposed to crude petroleum or its products with nonexposed workers revealed a significant excess among the former of cancers of esophagus and stomach (ICDA 150 and 151), and trachea, bronchus and lung (ICDA 162). The excess mortality in the exposed workers was generally consistent in comparisons specific for geographic area and refinery/exposure subgroup, although small numbers of deaths in some categories introduced difficulties in interpretation. Further, exposed workers exhibited increasing stomach and lung cancer mortality with increasing duration of employment. No excess of intestinal (ICDA 153-154) or other digestive organ (ICDA 156-159) cancer was apparent in the exposed group. These results tend to support the hypothesis that exposure to crude petroleum and its products increases the risk of death from cancer of the stomach and lung, but not from cancers of the intestine and other digestive organs.

A small increase in the risk of intestinal cancer among exposed workers could have been missed. It was estimated that the probability of detecting, at the 5% level of significance, a relative risk of 3 in the exposed group, given 42 intestinal cancer deaths and 62% of the study population in the exposed group, was 0.82.

The two-fold increase in lung cancer mortality is consistent with a number of other studies of occupational exposure to petroleum or aromatic hydrocarbons.¹⁷⁻²² A similar increase in stomach cancer mortality has not been

described.³ Two studies of occupation and gastric cancer failed to incriminate occupations involving exposure to petroleum or aromatic hydrocarbons²³⁻²⁵ — however, a study of purgative use by stomach cancer patients and their controls revealed a significant excess of liquid paraffin use among the cancer patients.²⁶

The second hypothesis tested by this study, that refinery workers have increased cancer mortality, particularly of the intestines and other digestive organs, is also supported by the results, although the absence of a positive relationship with duration of exposure, and inconsistencies in the refinery/exposure subgroup comparisons weaken the evidence.

In this study bias could have contributed to the observed differences because it was not possible to examine the comparability of the exposed or refinery groups and their controls for demographic factors or specific factors, currently known to be associated with particular cancers. For example, differences in smoking habits could underlie at least part of the excess risk of lung cancer in the exposed workers and might afford an explanation of the excessive lung cancer in office workers. Since stomach cancer rates are inversely related to the social class,²⁷ it is important to compare the exposed and nonexposed groups for this variable, in order to rule out a concomitant of some attribute of social class other than exposure to petroleum as the explanation of the results. Ethnic origins of workers in both groups should also be compared.

Social class differences between the refinery workers and controls should be ruled out as an explanation for the increased risk of intestinal cancer in the refinery group.¹⁷ However, major social class differences between the refinery/exposure groups and their controls seem unlikely as explanations for any of the observed differences, since the relationships between social class and lung and stomach cancer on the one hand and intestinal cancer on the other, are in opposite directions.²⁸⁻³³ The refinery/exposed and non-refinery/nonexposed groups are different, yet overlap to a degree that makes it improbable that any social class imbalance in the two sets of comparison groups would be in opposite directions.

A number of methodological problems could have either weakened observed differences or resulted in failure to detect real differences. One of the greatest defects of this study was the impossibility, given current company records, of following short-term employees. It is unlikely that much useful information was lost by the exclusion of employees with less than five years service, since this group was young and very few cancer deaths occurred in employees under the age of 40. However, inability to follow employees with five to 15 years service is a more serious matter. In this study, since the proportions of lost employees with five to 15 years service were lower in the two study groups than in their respective controls, it is unlikely that losses contributed to the observed differences. It is possible, however, that differential loss could have contributed to failure to detect real differences if occupational exposure were related both to leaving employment and subsequently to death.

Another difficult problem was the accurate categorization of employees according to exposure to petroleum and its products. Error in classification cannot have

biased the study since classification was carried out in ignorance of the fact and cause of death; but such errors could have contributed to failure to detect real exposure hazards. The likelihood of misclassification of exposure was enhanced by the lack of availability of employee job histories prior to the 10-year observation period. Thus, it was possible that employees, older ones particularly, could have moved from the exposed or refinery classes prior to the start of observation, and were classified as nonexposed or nonrefinery regardless of where the majority of their working years had been spent. Movement in the reverse direction may have occurred also. During the 10-year period, only 1.6% of the study population changed exposure status, and this problem may have been no more frequent prior to 1964.

The cause of death information on the death certificate is always subject to inaccuracy. The consequence for this study of using death certificate information should not have been bias, since the determination of cause of death was done independently of knowledge of exposure/refinery status. However, any inaccuracy which reduced the number of cancer deaths in the study increased the difficulty in detecting real differences. Morbidity data were not available to us, but their use would be preferable, because access to MII morbidity data can provide some indication of accuracy of diagnosis. Further, the study of cases rather than deaths is desirable when studying a cancer (e.g., of intestines and rectum) with an appreciable survival rate.

The problems which have beset this study are common in studies of occupational hazards in man. They cannot be overcome until industry accepts responsibility for the maintenance of complete records, including changes in job for each employee throughout his period of employment, and developing and using objective methods of measuring exposure, both in terms of quantity and quality. It is important for industry, with government and union cooperation, to develop record linkage methods for following workers from one employer to another and for unions and industry to cooperate in obtaining information on demographic factors, hobbies and personal habits, necessary for the rational interpretation of occupational studies. Imperial Oil is presently updating this mortality study and is in the process of designing a cancer morbidity study.

Summary.

The cancer mortality experience from 1964 to 1973 of employees of the Imperial Oil Limited was examined in a cohort study. Employees in jobs which exposed them on a daily basis to crude petroleum or its products, compared with nonexposed employees, were found to have more than three times the risk of esophageal and stomach cancer and about twice the risk of lung cancer. In the exposed group, increasing risks of both cancers occurred with increasing duration of employment. In the absence

of more complete information on the similarity of the exposed and nonexposed employees, these results cannot be ascribed with certainty to a carcinogenic effect of petroleum. However, there was no other clear explanation for the results, and further study is required.

When refinery workers were compared with non-refinery workers without consideration of exposure to petroleum in either group, the refinery workers were found to have twice the risk of cancer of the intestines (including rectum) and other digestive organs. No relationship with duration of employment was evident. Although the increased intestinal cancer mortality in the refinery workers was not consistent, bias was not an obvious explanation for the observed relationship. Therefore, the presence on a refinery site of a carcinogen other than petroleum has not been ruled out, and further study is urged.

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