

CAUSE-SPECIFIC MORTALITY
AMONG EMPLOYEES AT THE CHEVRON
RICHMOND AND EL SEGUNDO REFINERIES

Submitted to
Standard Oil Company of California

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EXECUTIVE SUMMARY

Environmental Health Associates, Inc. (EHA) conducted a mortality study of 14,179 current and former Chevron USA employees at the Richmond and El Segundo refineries. The study group, or cohort, consisted of all persons working at either refinery for a minimum of one year before 31 December 1980 and who worked there at least one day between 1 January 1950 and 31 December 1980. We were able to determine the vital status of 95.0% of the cohort, a percentage considered acceptable for studies of this kind. Of the 2,242 known deceased, we obtained death certificates for 2,192 (97.8%). The observed mortality of the cohort, by cause, was compared to the expected based on the U.S. mortality rates, standardized for age, race, sex and calendar time. Additional analyses by sex, race, length of employment, year of hire, latency, refinery, and job title/location subcohort were performed.

For the entire cohort, mortality from all causes was 72.4% of that expected, a value which was statistically significant. This overall deficit is greater than values typically observed for occupational cohorts, who commonly experience mortality of 80-90% of the national norm. In addition to the overall mortality rate, significantly lower rates were found for all forms of cancer combined, digestive cancer, lung cancer, heart disease, non-malignant respiratory disease, diseases of the digestive system, and accidents. For a number of causes, including all cancers combined, digestive system cancer, and lung cancer, the study had sufficient power to detect a 30% or more increase in risk, had such an increase existed.

While several disease categories showed non-significant mortality excesses, only one - lymphopoietic cancer - exhibited a pattern of increased risk suggestive of a possible relationship to an occupational exposure. The excess appears confined to cancers of lymphatic tissue (not leukemias) at Richmond, and only among persons hired prior to 1948. Further investigation will be required to determine whether or not the excess is related to any particular job or work location.

In conclusion, the study has provided considerable reassurance concerning the long-term health of Chevron USA refinery employees at Richmond and El Segundo. Their overall mortality is low, and they show no suspicion of excess risk for a number of cancers (including lung, kidney, and digestive organs) which have been implicated in other refinery studies reported in the literature. Only a marginal excess in lymphopoietic cancer appears to warrant further investigation at this time.

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INTRODUCTION

Literature Survey of Epidemiologic Studies of Refinery Workers

A number of epidemiologic studies of petroleum refinery workers have been conducted. These studies were different in size and design, and covered different periods of time. The following is a brief summary of the major epidemiologic studies of petroleum refinery workers.

The first large-scale industry-wide study [Tabershaw/Cooper Associates, 1974] was sponsored by the American Petroleum Institute, and consisted of 20,163 workers employed in 17 refineries for at least a year between 1 January 1962 and 31 December 1971. The study ascertained vital status of 94% of the cohort as of 31 December 1971 and identified 1165 deaths. The mortality of the cohort was compared to that of the U.S. males in terms of the standardized mortality ratio (SMR). A brief discussion of this statistical procedure is given on page 22. The overall SMR for the entire cohort was significantly low. Men with the lowest estimated exposure to atmospheric hydrocarbons had the highest SMR from cardiovascular and renal diseases, digestive cancer and ulcers of the stomach and duodenum, although none of the SMRs was statistically significant. The report suggested that this finding might have been a function of differing physical demands in job categories, with different exposures, and of social and economic differences in the different exposure groups. On the other hand, mortality from a number of causes of death appeared to be exposure-related (increased mortality with higher exposure), including respiratory cancer, lymphomas, and genital cancer, although none was statistically significant. Since mortality from lymphomas exceeded the expected value and appeared to be exposure-related, the report suggested additional investigations to determine

the possible relationship between lymphomas and employment at petroleum refineries.

A relatively small study was conducted on 1,205 men employed for more than five years in a Canadian oil refinery in East Montreal between 1928 and 1976 [Theriault and Coulet, 1979]. Of the total cohort, 190 (16%) were lost to follow-up and their vital status remained unknown at the end of the study. In this group of Canadian oil refinery workers, the overall mortality was lower than that in the general population, the overall SMR being 78.43. There was no significant difference in the total cancer mortality rate between the refinery workers and the Quebec population (SMR = 89.29). In particular, lung cancer was less frequent than expected (3 observed vs. 7.42 expected). However, analysis by latency indicated a significant excess of brain cancer among those with a latent period of less than 20 years (3 observed vs. 0.46 expected, SMR = 652); but no common exposure was found among these three cases. Finally, though cancer of the digestive system was not significantly elevated (12 observed vs. 10.22 expected), the report suggested that this finding, combined with an elevated number of deaths due to diseases of the digestive system, should be given further attention.

Hanis et al [1979] conducted a cohort mortality study of 15,032 active or retired male employees (1964-73) of a Canadian petroleum company to determine the cause-specific mortality experience of workers exposed to petroleum and its by-products. A total of 865 (6%) employees were lost to follow-up. During the 10-year period of observation, 1,511 deaths were identified in the cohort. Mortality from all malignant neoplasms in the exposed group was significantly above

that in the non-exposed. In particular, comparison of the exposed and non-exposed workers revealed a significant excess among the former of cancers of esophagus and stomach (3-fold risk), and trachea, bronchus and lung (2-fold risk). Furthermore, exposed workers exhibited increasing stomach and lung cancer mortality with increasing duration of employment. 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). Based on this observation, the authors concluded that "the presence on a refinery site of a carcinogen other than petroleum has not been ruled out, and further study is urged."

During the last few years, the National Cancer Institute (NCI) has published a number of proportional mortality analyses on members of the Oil, Chemical, and Atomic Workers International Union (OCAW) in Texas. The latest published report was based on 2,509 active and retired OCAW members who worked at three oil refineries in the Beaumont and Port Arthur areas in Texas [Thomas et al, 1982]. Deaths that occurred between 1943 and 1979 were identified from union membership records of the OCAW headquarters in Denver and from the records of union locals in Texas. Age-adjusted cause-specific Proportionate Mortality Ratios (PMRs) were calculated using the mortality experience of the U.S. general population as a standard. Excess mortality from stomach cancer occurred among active union members at Refinery A, and among active and retired union members at Refineries B and C. PMRs for leukemia, multiple myeloma, and other lymphomas were elevated, especially among retired workers. Mortality due to brain tumors was significantly elevated among active members at all three refineries and slightly elevated among retirees at Refineries A and C. Based on these PMR findings, the authors

concluded that 'oil refinery workers may have elevated risks of these cancers' and, in general, mortality from these cancers increased with length of employment and latency.

A mortality study of 34,781 workers employed for at least a year between 1 January 1950 and 31 December 1975 at eight oil refineries in Britain determined the vital status of more than 99% of the cohort [Rushton and Alderson, 1981a]. Of the 4,406 deaths identified during the observation period, cause of death was determined for all except four. Expected deaths were calculated based on the mortality rates for all males in England, Wales and Scotland, with adjustment for regional variation in mortality for the English and Welsh refineries. The observed overall mortality experience was significantly less than the expected (SMR = 84, $p < 0.0001$). Mortality from all cancers, lung cancer, heart disease, stroke, bronchitis, and pneumonia was also significantly low. On the other hand, significant mortality excess was found in all 8 refineries for cancer of the nasal cavities and sinuses, and for melanoma. Furthermore, in several refineries and several occupational groups, significant mortality excess was observed in cancer of the esophagus, stomach, intestines, rectum, and lymphosarcoma.

In the above cohort study, there was a slight deficit of observed leukemia deaths when compared with the expected based on national rates (30 observed vs. 31.96 expected). Because these oil refinery workers were likely exposed to benzene, a case-control study of all deaths with a mention of leukemia on the death certificate (36 cases) in the original cohort was conducted, with the specific objective to investigate the role of benzene exposure in these leukemia deaths [Rushton and Alderson, 1981b]. The potential benzene exposure of these cases

was compared with that of controls selected from the total refinery population. Although no information was available on measurement of benzene in the work environment, job histories were obtained and were used to allocate each study subject to a benzene exposure level of low, medium or high. When length of service was taken into consideration, the risk for those men with medium or high exposure to benzene relative to those with low exposure was 2-fold ($p=0.05$). Thus, the authors concluded that there was an increase in the risk of leukemia in the group to whose exposure to benzene was assessed as medium or high, but there was no evidence that the risk increased with length of service. Furthermore, the authors argued that, since no leukemia excess was found in the overall cohort study, the risk affected only a very small proportion of men within the refinery workforce.

A recent cohort mortality study consisted of 8,666 regular employees who worked at least one month during the period 1 January 1970 through 31 December 1977, and retirees who were alive as of 1 January 1970 at the Exxon Baton Rouge refinery and chemical plant [Hanis et al, 1982]. A total of 835 (9.6%) were lost to follow-up, and 1,199 were identified to have died. Of those identified as deceased, 1,075 (90%) were retired and the remaining 124 died while employed. Death certificates were obtained for 97% of the deceased. Expected death rates by cause were calculated using the U.S. death rates as the standard, adjusted for age, sex, race and calendar year. The study found a significantly low overall mortality for the entire cohort ($SMR = 92$). However, the authors noted that analyses by specific site of cancer revealed elevated SMRs for cancer of the kidney, testis, brain/central nervous system, pancreas and lymphopoietic tissue; although none of these elevations was statistically significant.

Because a previous study found an association between pancreatic cancer and employment in the oil refinery industry, as well as residence near refineries in Louisiana [Pickle and Gottlieb, 1980], and the observation that one additional death from cancer of the pancreas in this study would result in a significant SMR, examination of work history of all the pancreatic cancer deaths was conducted. However, the attempt failed to identify any specific agent associated with the excess.

Several studies have been conducted by the Epidemiology Department at Gulf Oil; some have been published and the others are in press. At the Cold Spring Harbor Laboratory Conference on the Quantification of Occupational Cancer, Wen et al [1981] presented the brain tumor mortality among employees at the Gulf Port Arthur refinery. The report was derived from a large cohort study consisting of some 17,000 employees who worked at Port Arthur between 15 June 1935 and 1 January 1978. The study found that SMRs for both all causes and all malignant neoplasms were less than expected. For malignant brain cancer, the SMR for white males was 76 (15 observed vs. 19.69 expected) and for non-white males 155 (3 observed vs. 1.93 expected); neither SMR was statistically significant. When benign brain tumors and brain tumors of unspecified nature were included with malignant brain tumors, the SMRs were 86 for white males and 92 for non-white males. However, a non-significant excess was found for those who worked for 20 years or more (SMR = 140). The relative risk for brain cancer comparing those with 20 years of employment to those with less than 20 years was 1.38 (not significant). Results for other causes of death were not reported in the paper.

In another paper, the mortality experience of all Gulf Oil Port Arthur refinery employees who worked at the benzene, ethylene, aromatic distillation hydrogenation or cumene units was reported [Tsai et al 1983]. Included in the analysis were 454 male employees who worked directly at these units and were exposed to benzene. In this group of workers, the SMR for all causes was only 54 (22 observed vs. 40.66 expected, $p < 0.01$). For all cancers, 4 deaths were observed with 8.18 expected (SMR = 49). Of particular interest was that no lymphopoietic cancer death was observed. The authors concluded that mortality from lymphopoietic cancer among the benzene-exposed refinery workers was not increased. However, it must be pointed out that the cohort was small and the power to detect a modest increase in either lymphopoietic cancer or leukemia was limited. For example, the least significant risk for lymphopoietic cancer that the study could detect (at $\alpha = 0.05$ and $\beta = 0.20$) was approximately 8-fold.

The mortality experience of the entire work force at the Gulf Oil Refinery located at Port Arthur, Texas, was published recently [Wen et al 1983]. The cohort consisted of 16,886 employees who worked at the refinery between 1 January 1937 and 1 January 1978. Vital status of the cohort as of 1 January 1978 was determined. The vital status of 1542 individuals (9.1%) was undetermined. Among the 4361 cohort members identified to have died, death certificates were not obtained for 287 (6.6%). Among the males, the overall SMR was 84 (statistically significant), and the total cancer SMR was 96 (not significant). Statistically significant mortality deficits were observed for cancer of the digestive system, cancer of the bladder, and lymphosarcoma and reticulosarcoma. A significant excess was detected for bone cancer (11 observed vs. 5.37 expected, SMR = 205). Slight, non-significant excesses were also found for cancer of skin (SMR = 122,

16 observed), cancer of kidney (SMR = 112, 22 observed), cancer of eye (SMR = 286, 2 observed), Hodgkin's disease (SMR = 245, 16 observed), leukemia (SMR = 114, 38 observed), and cancers of other lymphatic tissue (SMR = 115, 20 observed). Significant deficits were observed for several non-malignant diseases: disease of the circulatory system (SMR = 79, 2036 observed), non-malignant respiratory disease (SMR = 68, 203 observed), and accidents (SMR = 77, 261 observed).

Some preliminary results from the American Petroleum Institute-Memorial Sloan Kettering Cancer Center (API-MSKCC) Prospective Morbidity and Mortality Study were released [Schottenfeld et al, 1981]. This program was a registry of mortality and cancer incidence for the petroleum industry and consisted of some 96,000 employees from 19 U.S. companies. Deaths among both active (unless transferred to non-participating divisions) and retired employees and cancer incidence among active employees during 1977 and 1979 were reported to MSKCC by participating companies. Cause-specific mortality was compared to U.S. death rates and site-specific cancer incidence to the Surveillance, Epidemiology, and End Results data of the National Cancer Institute, adjusted for age, sex and race. The overall mortality of the study population was significantly lower than that of the U.S. population (SMR = 55). Mortality from heart disease, strokes and accidents was decreased significantly. On the other hand, mortality from cancer of the rectum, brain, and melanoma was elevated, although not statistically significant. Lung cancer mortality was significantly lower than expected. Cancer incidence data indicated an elevated incidence of cancer of the larynx but a deficit in lung cancer, although neither was statistically significant. Statistically significant increases in cancer incidence were observed for: acute and chronic lymphocytic leukemias in refinery workers

(Standardized Incidence Ratio (SIR) = 274); multiple myeloma among petrochemical workers (SIR = 552); and melanoma among workers in the middle Atlantic region (SIR = 278).

A historical cohort mortality study was conducted of 259 male employees of a petrochemical plant (converted from a petroleum refinery) where benzene was used in large quantities [Decoufle et al 1983]. The cohort consisted of all men employed at the plant between 1947 and 1960, and their mortality experience was followed through 1977. Four deaths from lymphatic and hematopoietic cancer were observed, when only 1.06 was expected, to produce an SMR of 377 (statistically significant). Three of these four deaths were from leukemia, compared to the 0.44 expected, for a leukemia SMR of 682 (statistically significant). Of the three leukemias, one was chronic lymphocytic, one acute monocytic, and one acute myelomonocytic. A review of medical records revealed that one of the leukemia cases had a history of multiple myeloma. This observation was of considerable interest, since the fourth death from lymphatic and hematopoietic cancer was due to multiple myeloma. The authors viewed this as a possible link between benzene and multiple myeloma. The authors also suggested an etiologic role for benzene in the pathogenesis of tumors of B-cell lineage and recommended broader examinations of lymphoreticular neoplasms in persons similarly exposed.

A recent cohort mortality study of all persons who were employed at least five years in a Texaco refining, petrochemical or research facility and who worked sometime between 1 January 1947 and 31 December 1977 was reported [Divine et al, in press]. The white male cohort consisted of 19,077 individuals from 20 locations, with some 43% from the Port Arthur facilities. As of 31 December 1977, there

were 4,024 individuals identified to have died and the vital status of 444 (2.3%) remained unknown. Death certificates were obtained for all except 152 (3.8%) of the 4,024 decedent white males. The overall SMR was 72 (statistically significant) and the all-cancer SMR was 73 (statistically significant). Significant deficits were observed for cancer of the digestive system (SMR = 67, 215 observed), cancer of the lung (SMR = 58, 182 observed), and cancer of the bladder (SMR = 54, 19 observed). On the other hand, non-significant excesses were observed for a number of site-specific neoplasms. For benign neoplasms, the SMR was 144 (20 observed). Of these, 12 were brain tumors, yielding an SMR of 130. The SMR for cancer of the brain and central nervous system was slightly elevated at 108. Other causes of death for which SMRs were greater than 100 were cancer of the pancreas (SMR = 104, 62 observed), Hodgkin's disease (SMR = 106, 13 observed), leukemia (SMR = 113, 48 observed), and cancer of other lymphatic tissue (SMR = 111, 25 observed). Significant mortality deficits were found for several non-malignant causes of death: diseases of the circulatory system (SMR = 76, 1975 observed), non-malignant respiratory disease (SMR = 50, 159 observed), diseases of the digestive system (SMR = 54, 141 observed), and accidents (SMR = 51, 152 observed). Analysis was also carried out for individual facilities. The only noteworthy finding was the SMR for benign neoplasms for Port Arthur facilities of 195 (13 observed), statistically significant.

Mortality experience of the non-white males and the females was also reported [Divine and Barron, in press(a)]. There were only 176 deaths among the non-white males. The overall SMR was 69 (statistically significant). The total cancer SMR was 69 (statistically significant). No excess was observed for any of the causes of death examined. Among the females, only 77 deaths were observed. The

overall SMR was 73, statistically significant. The only excess observed was that for lung cancer (SMR = 174, 5 observed), but the excess was not significant.

The Texaco cohort study was followed by a series of case-control studies within the cohort [Divine and Barron, in press(b)] to examine pancreatic cancer, brain neoplasms (malignant, benign and unspecified), leukemia, lymphatic cancer (excluding leukemia), stomach cancer and kidney cancer. For pancreatic cancer, the following processes or units were found to experience a significantly high relative risk: those ever employed at the asphalt plant (RR = 2.9); those with their longest job held at the asphalt plant (RR = 4.4); and those with the longest job held at packaging and shipping (RR = 2.7). For brain tumors, the quality control laboratories experienced an RR of 3.0 (ever employed) and an RR of 4.1 (longest job held); the paraffin, refrigeration and ammonia employees experienced an RR of 3.4 (ever employed); and the lube oil refinery experienced an RR of 3.6 (ever employed) and an RR of 4.1 (longest job held).

For leukemia, three process units were identified to have significantly high RR: utilities (RR = 2.6 for "ever employed" and 4.6 for "longest job held"); asphalt plant (RR = 2.6 for "ever employed") and lube oil refinery (RR = 3.2 for ever employed). For lymphopietic cancer, excluding leukemia, those ever employed at the fluid catalytic cracking unit experienced a significant RR of 3.1. For stomach cancer, those ever employed at the maintenance and yard had a significant RR of 3.1, those with the longest job at gas plant had a significant RR of 5.3 and those who ever worked at lube oil refinery had an RR of 5.1. For kidney cancer, no process unit was identified to have a significant RR.

Summary of Literature Survey

A number of the studies reviewed above have certain limitations, either because of study design or because of the particular data source available to the investigators. For example, the API study [Tabershaw/Cooper Associates, 1974] had a very short follow-up, and there were problems in the exposure classification used in that study. The Theriault and Goulet [1979] study consisted of a very small cohort, and the percentage lost to follow-up was extremely high (16%). The Hanis et al [1979] study suffered from the lack of availability of employment job histories prior to the ten-year observation period. The Thomas et al [1982] study inherited all the problems associated with proportionate mortality (PMR) studies, in terms of both methodology and completeness of death ascertainment. The Exxon study [Hanis et al, 1982] had a short follow-up and deaths among terminated employees were not ascertained. The API-MSKCC program [Schottenfeld et al 1981] covered only 3 years of observation, and ascertainment of deaths or cancer cases was likely incomplete. The Gulf study of benzene workers [Tsai et al 1983] had very few study subjects.

In spite of these limitations, these epidemiologic studies have revealed a number of cancer sites with significant excesses among individuals exposed to petroleum and its by-products, when compared to the general population or to non-exposed employees. Table 1 summarizes the site-specific cancer risk by study. The table indicates that several cancer sites have been implicated in more than one study, and suggests that refinery workers may be at higher risk of a number of cancers: in particular, cancer of the respiratory system, stomach, lymphopoietic tissues and, perhaps, brain. However, it must be pointed out that

there are a number of conflicting findings among the studies surveyed (such as inconsistency in lung cancer risk), and there is no clear, repetitive problem. Furthermore, none of the studies has yet identified any specific agent(s) responsible for any excess, except for the relationship between leukemia and benzene identified by Rushton and Alderson [1981b]. As such, further epidemiologic investigations with adequate sample size, sufficient follow-up and well-documented work history in the petroleum industry are needed, and the continuation of monitoring the health of refinery workers is essential.

MATERIALS AND METHODS

In spring of 1981, Standard Oil Company of California (SOCal) requested that Environmental Health Associates, Inc. (EHA) assess the feasibility of a cohort mortality study at the Richmond and El Segundo refineries. The feasibility study was completed and findings reported to SOCal in May 1981. In addition, at SOCal's request, a proposal for an epidemiologic study was also submitted.

Cohort Definition

Based on the findings of the feasibility study, EHA proposed to study the cohort of all individuals who had completed one year of work at either refinery by 31 December 1980 and who worked for at least one day between 1 January 1950 and 31 December 1980. The precise criteria for cohort inclusion were as follows:

- (1) employed in operating and maintenance, clerical, technician and unclassified jobs at either the Richmond or El Segundo refineries;
- (2) employed on 1 January 1950 or subsequently, through 31 December 1980; and
- (3) employed for at least one year at the refinery by 31 December 1980.

Data Collection

The cohort was to be constructed by using employment records (primarily Form 307) at the two refineries, corporate offices and other SOCal record storage facilities.

For efficiency, EHA proposed coding only the first and last jobs (i.e., job titles, locations and dates). By not coding the entire work history, it is possible to miss specific jobs of high risk. However, we felt that this would correctly identify most sub-cohort members, yet offer considerable savings in both time for completion and cost of coding. It was also recognized that should the study generate enough interest in certain causes of death, any further investigation would require either a case-control study (with complete job coding of cases and controls) or, less likely, a re-analysis of the entire cohort, but after adding complete job coding.

SOCal accepted the EHA proposal in October 1981. Data collection began immediately with microfilming of employment records at Richmond, El Segundo, Oakland, San Francisco, La Habra and other locations, and was completed in March 1982.

Employment records utilized in the study included the following:

- Form 307 - Employment Application
- Form 308 - Employment Changes
- Form 76A - Salary or Assignment Change
- Form 400 - Personal (Personnel) Experience Record
- Form 310 - Employee Development Guide
- Form 439 - Unemployment Insurance Termination Guide

These records generally included the following information: name, social security number, sex, date of birth, date of hire (or service date), date of separation, and work history summary (Form 307). Some records had both work history summaries and separate personnel action forms (Form 76A), which contained more detailed work history information. The information from these sources was used to reconstruct work histories. Dates of death and death certificates were available for some persons who died while employed or after retiring.

Personnel records were collected for all individuals who met the criteria of cohort eligibility. To ensure that all eligible employees would be included, any questionable records were also collected so they could be reviewed carefully later at EHA offices. EHA staff microfilmed approximately 20,000 employment records, and collated them into individual unit files.

Data Reduction

Using these personnel records, the following items were abstracted onto a coding form for entry into a computer:

- ° worker's name
- ° social security number
- ° date of birth
- ° sex
- ° race (if known)
- ° date of hire
- ° date of separation
- ° employment status (e.g., active, separated, retired, etc.)
- ° vital status
- ° vital status source
- ° date of death (if applicable)
- ° the first and the last jobs (work location, job title, and dates)

An example of the coding form, coding specifications and instructions are attached in Appendix 1, 2 and 3, respectively.

Data reduction was divided into two phases. During the initial phase, only information that was pertinent to vital status follow-up through the Social Security Administration was coded. This included name (first six letters of the last name), social security number, and the study subject identification number for all individuals who had separated from employment with Chevron prior to 31 December 1980. The second phase included the coding of all demographic information and work histories.

Some employment records were missing a date of hire (i.e., date started in first job at Chevron). Because this could be different from the employee's company "Service Date", additional efforts to retrieve this date were undertaken through SOCal corporate headquarters. When no further information was available, the following rules were applied: either the first entry on the work history that identified an individual at Chevron was used, or if this was not available, the service date was used as the hire date.

The data were then keypunched, key verified, and entered onto computer tapes. Once on computer tapes, the records were edited extensively. Duplicate records were identified and eliminated, computer edit programs were used to check the internal consistency of the data, and impossible codes/values were reviewed. Additionally, the edit programs checked against the employment history of each individual to ensure the cohort inclusion criteria were satisfied.

Coding Quality Assessment

To assess the accuracy of coding, a 10% systematic random sample of the records was re-coded by an independent coder. Inter-observer coding provides a measure of coder agreement, which is also an assessment of coding accuracy.

A comparison of selected demographic and all work history variables revealed 96% agreement between coders. Appendix 4 shows the rate of coder agreement for each variable examined.

Cohort Verification

To a large extent, the validity of an epidemiologic study depends on the quality of data. Ideally, the data should be 100% complete. Short of that, the potential effects of any incompleteness should be assessed to insure that no systematic bias would result from such incompleteness. Since historical employment records are the major source of data in cohort mortality studies, and the question of how complete the historical records are is always a concern, verification of cohort completeness is an important quality control in studies such as this. The primary purpose of the verification is to detect any systematic omissions or significant gaps in records copied.

EHA and SOCal investigated the possibility of using Social Security Quarterly Reports (Form 941) for cohort completeness verification, and found that method not practical because these reports were not specific to locations within the state. The best data source for verification within the company but independent of the source for data collection, was employee year-end tapes from the centralized Personnel/Payroll System. These are computer tapes made at the end of each

calendar year of all SOCal employees who had some employment or retirement activity in that year. Since, by definition, a cohort member had to have worked a full year, only those names of individuals who appeared on two consecutive year-end tapes at the Chevron refineries in Richmond or El Segundo were considered eligible for our cohort.

Three sets of year-end tapes (1965-66, 1970-71, 1977-78) were used for cohort verification, after selecting the years randomly. A total of 7097 individuals were generated from these tapes. Of these, 279 (3.8%) were not included in the cohort (183 from Richmond and 96 from El Segundo). The names of the 183 Richmond employees were submitted to SOCal corporate medical personnel for a search on SOCal's computerized Personnel Data Retrieval System, and 148 of these individuals were found in the computerized system. For 61 individuals, the information provided by the computerized system was not specific enough to determine whether they were eligible for the cohort. Eighty-seven were found to be eligible, but were missed in our data collection. It was not determined whether these files were not present in SOCal files at the time of microfilming or they were inadvertently left out from the microfilming. The remaining 35 names were not located in the computerized system. The small number of potential missed cohort members was not over-represented in any particular occupational department or file storage facility. We do not believe that any bias in cohort ascertainment would likely result. Based on the Richmond results, it was decided that it would not be necessary to verify the eligibility of the 96 names from El Segundo. Overall, this small percentage of "missed" records should not have any untoward effect on the results.

Employment Classification

With SOCal's and Chevron's assistance, EHA staff developed a dictionary of Chevron refinery job titles and locations (e.g., department, division, plant, laboratory, etc.). During the coding process, whenever a new job title or location was encountered in an employment record, it was assigned a code and entered into the job title or location dictionary. This procedure generated some duplications, since some titles were essentially synonyms or abbreviations or the same job or location. However, this approach also guaranteed the most complete list of all current and historical job titles and location descriptors. The resulting dictionaries consist of 3324 jobs and 1699 locations for the two refineries combined, with an estimate of 30-40% duplicates between the two refineries (see Appendix 5).

These job and location codes were then classified into subgroups based on type of work. For location codes, the following six subgroupings were utilized: (1) Administration; (2) Laboratory; (3) Operating; (4) Maintenance; (5) Package, Utilities, and Warehouse; and (6) Marketing and Transportation. For job codes, the following seven subgroupings were utilized: (1) Administrative/Management; (2) Clerical/Office Support; (3) Laboratory; (4) Operating; (5) Maintenance; (6) Custodial/Plant Protection and other; and (7) Supervisory/Foreman (unknown department).

Vital Status Follow-up

It was necessary to determine whether those workers who had terminated their employment (including terminees, transferred, and retirees) prior to 31 December 1980 were still living or whether they had died in the interim between

termination of their employment and the end of the study. The procedure used in the vital status follow-up of former employees is presented below. Although Figure 1 summarizes the results of the various vital status procedures for only individuals satisfying the cohort criteria, the following description includes all individuals for whom vital status follow-up was initiated.

Social Security Administration Vital Status Follow-up

As described previously, the data reduction was accomplished in two phases. As soon as the first phase, the coding of name, social security number, and study identification number, was completed, vital status follow-up through the Social Security Administration (SSA) was initiated.

It was necessary to conduct SSA vital status follow-up on 8,964 former employees who had terminated their employment prior to the study cutoff date. The remaining individuals were known to be living as of the study cutoff date (31 December 1980), either because they were actively employed, or retired and receiving benefits as of 31 December 1980, or because they had died after that date. The SSA search identified 6,889 individuals as alive, 514 as deceased and 1,561 individuals with unknown vital status.

Because over 11% of the cohort was still of unknown vital status following the SSA search, further follow-up was initiated.

California Automated Mortality Linkage System (CAMLIS)

The University of California at San Francisco (UCSF) maintains a computerized data base identifying individuals who died in the State of California, along with the state death certificate registry number for death certificate retrieval. This system, known as CAMLIS, is complete starting in 1966. Because the two Chevron refineries are located in California, and it was felt that cohort members would likely stay in California following termination or retirement, EHA submitted the remaining individuals in the cohort with unknown vital status to match against the CAMLIS data system.

A group of 1313 cohort members with unknown vital status and 160 cohort members who were believed to be deceased, but for whom we had not retrieved a death certificate, were also submitted for the CAMLIS search. Of these 1473 individuals, 49 were identified as deceased and their death certificate registration numbers were obtained.

Vital Status Follow-up through the California Department of Motor Vehicles (DMV)

DMV follow-up was pursued following the completion of the SSA follow-up. Driving records were requested for 1,183 vital status unknowns. Persons were considered living if they had renewed their drivers' license or if they had received any citations on or after 31 December 1980. As a result, 473 persons were identified as living, while the vital status of 710 persons remained unknown. No individuals were identified as deceased using this procedure. This reduced the category of "vital status unknown" to 5%, a level acceptable for the purposes of this study.

Death Certificate Acquisition

From either the appropriate state's vital statistics department, from the employment records, or from SOCal corporate headquarters, we retrieved death certificates for 2,242, or 97.82% of the persons identified as deceased. The majority of decedents died in California. EHA maintains microfiche of the California Death Registry, which identified the death certificate registration number for reported deaths in California. After obtaining the registration number, the certificates were retrieved by EHA from the Office of Vital Statistics in Sacramento.

EHA's nosologist coded all death certificates according to the 8th Revision of the International Classification of Diseases by underlying cause of death and up to four contributing causes [World Health Organization, 1967 and 1969]. The decedent's place of usual residence was also coded. Information from the death certificate, which included date and cause of death, was keypunched, verified, updated to the computer file and edited again to ensure data accuracy prior to analysis.

Statistical Procedure

The most common summary index for assessing the risk of death in a cohort study is the Standardized Mortality Ratio (SMR). Basically, the number of deaths occurring in the study population during the observation period is compared with the number of deaths which would have been expected if, after adjusting for age and time period, the study population had had the same mortality experience as a comparable non-exposed population. During the observation period, the

cohort members entered the study at different points in time, and some died prior to the end of follow-up. For these reasons, cohort members were observed for various lengths of time. Therefore, both the number of persons, as well as their individual length of time under observation, must be considered.

To utilize fully the period of observation for each member and to properly weight the SMR, the analysis used the concept of "person-years". The basic unit of computation is the number of years each employee was followed, from the anniversary date (one year of service) or 1 January 1950 (whichever was later) to the end of the study period or the date of death (whichever was earlier). For those "lost to follow-up", person-years of observation were counted up to the last date of contact, which was usually the termination date or the last driver's license renewal date. Thereafter, these individuals were taken out of the analysis. This amounts to assuming that the mortality experience of these individuals was similar to that of the rest of the cohort. Each year (or fraction thereof) contributed by an individual worker was classified by age, race, sex, and calendar year, and these person-years of all workers were then summed up by age, race, sex and calendar year. The U.S. national age-cause-race-sex-specific mortality rates for 5-year time periods from 1950-80 were applied to those person-years to obtain the number of deaths from a particular cause to be expected from an equal number of person-years of the same race and sex and similar in age and calendar year.

SMRs were computed by expressing the actually observed deaths as percentages of the expected. An SMR higher/lower than 100 indicated an excess/deficit in mortality. The deviation from 100 was tested to determine whether it was sta-

tistically significant at the 0.05 and 0.01 level. Both 95% and 99% confidence limits for the SMRs were also calculated. However, only the 95% confidence limits are presented in the tables. The actual computation was performed using a standard computer program [Marsh and Preininger, 1980].

RESULTS

Descriptive Statistics

Included in the analysis were 14,179 individuals who satisfied the cohort criteria. The sex and race distribution of these 14,179 cohort members is presented in Table 2. The majority of the cohort were white males. Approximately 20% of the cohort did not have race information recorded in their employment files. A discussion on how to handle these individuals is provided in the 'statistical procedure' section.

Table 3 presents the birth year distribution for all cohort members. The majority of the cohort was born during the 1920s through the 1940s. Only some 10% were born after 1949.

Distribution by year of hire for the two refineries and for the entire cohort is given in Table 4. Major hiring at the two refineries occurred in the late forties. Almost 40% of the cohort were hired before 1950, thus providing a possible latency of up to 30 years for this group.

Distribution of age at hire for the entire cohort is shown in Table 5. More than 70% of the cohort were hired before age 30. On the other hand, less than 5% were hired after age 40.

Table 6 presents the distribution of the terminated and transferred cohort members as of 12/31/1980, by year of termination. The employment status of the entire cohort as of 12/31/1980 is shown in Table 7. Nearly 25% (3465) of the cohort were active employees at either refinery as of the last day of the study.

A total of 3144 cohort members retired during the study period, and 5979 terminated their employment with Chevron. The remaining 1126 individuals were transferred to other Chevron refineries or other Chevron companies. Approximately 3% (465) died as active employees.

The distribution by length of employment for the entire cohort is presented in Table 8. Over 47% of the cohort was employed for 10 years or more, and 33.5% were employed for less than 5 years. The average length of employment for the entire cohort was approximately 14 years.

The vital status of the cohort as of 31 December 1980 is given in Table 9. As of the end of the study period, 11,177 or 78.83% were still alive. A total of 2292 individuals were identified to have died during the study period. Among these, death certificates were obtained for all except 50 deaths (2.18% of all deaths). At the end of the study, the vital status of 710 individuals (5.01%) remained unknown. The majority of these individuals were terminated employees.

Tables 10 and 11 provide a breakdown of the decedents by year of death and age at death, respectively. As expected, there is a temporal increase in the number of deaths, because of the aging of the cohort.

Cause-Specific Mortality Analysis

As mentioned earlier, race for 2772 individuals was not available from their employment records. However, there were very few known non-whites (772) among the Chevron employees at the two refineries included in this analysis. In order not to bias any race-specific analysis, race information from death certificates was not utilized. For the analysis, those individuals with unknown race (2,772) were assumed to be white.

In the study, a total of 2,292 deaths were identified. Death certificates were obtained for 2,242 decedents. The 50 deaths without death certificates, but with dates of death, were coded as cause unknown. These 50 deaths were included in the calculation of overall SMRs, but not in any cause-specific SMRs.

Entire Cohort

The observed and expected deaths, by cause, SMRs and their 95% confidence limits for the total cohort are presented in Table 12. The 2292 deaths observed produced an overall SMR of 72.4, which was significantly low ($p < 0.01$) in comparison with the U.S. national mortality experience. Furthermore, the confidence limits indicate that we are 95% confident that the overall mortality of the total cohort was at least 25% less than that of the U.S. population as a whole.

Mortality from cancer of all sites combined was also significantly lower than the U.S. experience (462 observed vs. 610.70 expected, $SMR = 75.7$). The deficit came primarily from the following sites: cancer of buccal cavity and pharynx ($SMR = 47.0$, $p < 0.05$), cancer of the digestive system ($SMR = 71.6$, $p < 0.01$), and cancer of the lung ($SMR = 66.9$, $p < 0.01$). Non-significant deficits were also observed for several other sites, including cancer of the prostate, cancer of the bladder, Hodgkin's disease, and leukemia.

Slight, but non-significant, increases in mortality were found in cancer of the brain (22 observed vs. 17.48 expected), lymphosarcoma and reticulosarcoma (17 observed vs. 13.43 expected), and other lymphatic tissue cancer (20 observed vs. 14.12 expected).

Mortality from cancer of the larynx ($SMR = 99.6$), cancer of the skin ($SMR = 92.5$), cancer of the breast ($SMR = 101.8$) and cancer of the kidney ($SMR = 87.7$) was similar to the expected.

Both benign neoplasms and disease of the blood showed a non-significant mortality deficit (SMR = 61.5 and 85.2, respectively). Statistically significant mortality deficits were observed for a large number of non-malignant causes: diseases of the nervous system (SMR = 47.6, $p < 0.01$), diseases of the circulatory system (SMR = 73.6, $p < 0.01$), non-malignant respiratory diseases (SMR = 55.7, $p < 0.01$), diseases of the digestive system (SMR = 64.7, $p < 0.01$), diseases of the genito-urinary system (SMR = 49.8, $p < 0.01$), senility and ill-defined conditions (SMR = 27.2, $p < 0.01$), and accidents (SMR = 71.2, $p < 0.01$).

Among all the causes of death examined, mortality from only one cause, suicide, was significantly elevated. In the total cohort, 88 deaths were attributed to suicide, compared to 68.94 expected. The increase was significant at the 0.05 level.

Richmond Refinery

Table 13 shows the mortality pattern of the Richmond refinery employees, whose overall mortality experience was significantly better than the U.S. population (SMR = 74.1, $p < 0.01$). Similar significant deficits were also observed for all cancers combined (SMR = 77.5, $p < 0.01$), cancer of the digestive system (SMR = 76.0, $p < 0.01$), and lung cancer (SMR = 62.8, $p < 0.01$).

Non-significant mortality increases were detected for cancer of the brain (15 observed vs. 11.16 expected), lymphosarcoma and reticulosarcoma (13 observed vs. 8.59 expected) and other lymphatic tissue cancer (15 observed vs. 8.98 expected). Mortality from other cancer sites (such as bladder and kidney) was either slightly less or similar to the expected.

Similar to the total cohort, Richmond Refinery had significant mortality deficits for a large number of non-malignant causes, including diseases of the circulatory system, non-malignant respiratory disease, diseases of the digestive system, diseases of the genito-urinary system, senility and ill-defined conditions, and accidents.

Mortality from suicide was elevated (56 observed vs. 44.39 expected). Although the corresponding SMR of 126.2 was not statistically significant, it should be noted that the lower 95% confidence limit was 95.1.

El Segundo Refinery

The mortality pattern of the El Segundo refinery employees is presented in Table 14. The overall mortality of these employees was 30% less than the U.S. population (SMR = 69.2, $p < 0.01$). Mortality from all cancers combined (SMR = 72.3, $p < 0.01$), cancer of the digestive system (SMR = 63.7, $p < 0.01$), and lung cancer (SMR = 74.0, $p < 0.05$) was significantly less than the expected. All other cancer sites showed either a slight non-significant deficit or a similar pattern to the expected. In particular, mortality from cancer of the brain, lymphosarcoma and reticulosarcoma, leukemia, and other lymphatic tissue cancer was as expected.

For a large number of non-malignant causes, the El Segundo employees enjoyed a significantly more favorable mortality experience than the U.S. population. For example, significant deficits were observed for several major categories, including diseases of the circulatory system, non-malignant respiratory disease, diseases of the digestive system, and accidents.

Similar to the employees at the Richmond refinery, El Segundo refinery employees also experienced an elevated mortality from suicide. A total of 32

deaths among El Segundo employees were observed, compared to the expected 24.55. However, the corresponding SMR of 130.3 was not statistically significant.

Analysis by Race and Sex

Table 15 displays the SMRs for the 12,783 white male employees, who made up the majority (90.2%) of the total cohort. The mortality pattern of the white male employees was essentially the same as the entire cohort. Significant mortality deficits were found for all causes combined, as well as several causes of death, including all cancers, digestive cancer, lung cancer, diseases of the circulatory system, non-malignant respiratory diseases, digestive diseases, and accidents. None of the SMRs was significantly elevated. However, non-significant excesses were found for cancer of the brain, lymphosarcoma and reticulosarcoma, other lymphatic tissue cancer, and suicide.

In the cohort, there were 624 white females from the two refineries. These white female employees contributed a total of 41 deaths, compared to 44.25 expected (Table 16). For cancer of all sites combined, 15 deaths were observed, whereas 12.58 were expected. The corresponding SMR of 119.2 was not significant. The SMR for cancer of large intestine was 296.7 (4 observed vs. 1.35 expected), but did not reach statistical significance at the 0.05 level. The only significant SMR among the white female employees was that for suicide: 4 deaths were observed and only 0.81 expected.

There were 718 non-white male employees in the cohort. Their overall mortality was less than 50% of the expected ($SMR = 48.7$, $p < 0.01$). The deficit appeared to come from both cancer, as well as diseases of the circulatory system (Table 17). No significant SMR was detected for this group.

There were only 54 non-white female employees from both refineries. No death occurred among them during the study period.

Analysis by Work Location

As mentioned earlier, the locations as well as the job titles for the first and last jobs were coded. These locations and job titles were classified into several broad categories. In this analysis, cohort members were grouped by location (either the first or last job). This analysis represented an attempt to identify any association, if any, between general work locations within the refineries and mortality. Detailed analysis (such as by length at a certain location, combination of location and job title, etc.) was deemed inappropriate, since only the first and last jobs were coded.

Table 18 shows the mortality of the sub-cohort of all employees in laboratory locations, by refinery. Among the 844 employees thus classified, the overall SMR for the two refineries combined was 74.1, significant at the 0.01 level. In addition, three causes of death showed a significant deficit: lung cancer (SMR = 26.6), diseases of the circulatory system (SMR = 76.8), and motor vehicle accidents (SMR = 15.9). None of the SMRs calculated was significantly elevated.

Approximately half of the cohort members (7838) were classified as having worked in maintenance locations. The overall mortality (SMR = 72.2) was significantly lower than expected (Table 19). Significant mortality deficits were also found for all cancers (SMR = 75.0), digestive cancer (SMR = 68.8), lung cancer (SMR = 65.9), diseases of the circulatory system (SMR = 73.6), non-malignant respiratory disease (SMR = 55.0), and accidents (SMR = 78.0). Slight, but non-

significant, mortality excesses were detected for cancer of larynx, cancer of brain, lymphosarcoma and reticulosarcoma, and other lymphatic tissue cancer.

Table 20 shows the mortality pattern of the 5,510 cohort members classified as operating (manufacturing) personnel. As with other groups, these refinery workers showed significant deficits in all causes (SMR = 79.5), all cancers (SMR = 82.5), digestive cancer (SMR = 63.8), cancer of prostate (SMR = 48.0), diseases of the circulatory system (SMR = 77.2), and non-malignant respiratory disease (SMR = 62.5). Non-significant excesses were found for cancer of larynx, lymphosarcoma and reticulosarcoma, other lymphatic tissue cancer, and diseases of the blood. A significant excess was detected for suicide (SMR = 150.5, $p < 0.05$).

Analysis by Latency

Long latent periods are usually required for chronic diseases to develop. In many situations, it is more appropriate to examine mortality experience only after a certain lag period has elapsed.

Table 21 presents the observed deaths and SMRs by cause for the total cohort by latency since hire. In general, persons followed for less than 10 years from hire date had exceptionally low SMRs. Among those followed for 10-19 years, the only significant SMR was for suicide (SMR = 148.7, $p < 0.05$). In the same group, SMRs for cancer of the rectum (131.8), lymphosarcoma and reticulosarcoma (180.7), other lymphatic tissue cancer (263.3) and emphysema (145.3) were elevated, but none was significant. For those followed for more than 20 years, no significant excess from any cause was found. In fact, most causes of death were either similar to or less than expected (significant or otherwise).

No obvious upward trend by latency was found, except for cancer of the digestive system. However, when the sub-categories within the digestive system were examined, no consistent trend was evident.

Analysis by Length of Employment

Table 22 displays the observed deaths and SMRs, by cause, for the total cohort by length of employment at the refineries. There was a slight downward trend of overall mortality, but the magnitude of the trend was small. More prominent downward gradients were observed for lung cancer, kidney cancer, and cirrhosis of the liver.

The only obvious upward trends were those for all lymphatic and hematopoietic cancer, and for suicide. However, for suicide the magnitude of the trend was very small. When the subcategories of lymphatic and hematopoietic cancer were examined, lymphoma and reticulosarcoma, Hodgkin's disease and leukemia showed a somewhat upward trend, albeit no death was observed for any of these three causes in the shortest length of employment (< 5 years) group. On the other hand, there was a downward trend for other lymphatic tissue cancer.

Analysis by Hire Date

The refinery workers in the study were potentially exposed to benzene, which has been implicated in some previous studies for increasing the risk of leukemias and lymphomas [Rinsky et al 1981, Wong 1983]. Occupational standards for benzene have undergone several changes historically. In 1947, the recommended benzene standard (8-hour TWA) was lowered from 100 ppm to 50 ppm, and was further reduced to 35 ppm in 1948.

In this analysis, the cohort was divided into those hired in or before 1948, and those hired after 1948. Table 23 displays the SMRs for these two groups. The most striking contrast was the SMRs for lymphatic and hematopoietic cancer (120.9 vs. 46.2). For lymphosarcoma and reticulosarcoma, the SMRs were 149.6 and 36.6, respectively. All 22 leukemia deaths occurred among those hired in or before 1948, and no leukemia death was observed among those hired after 1948. Similarly, all 6 deaths from diseases of the blood occurred among those hired in or before 1948, and none among those hired after 1948.

Similar analyses by hire date were performed separately for the refineries (Tables 24 and 25). The contrast in total lymphatic and hematopoietic cancer mortality and its sub-categories by hire date appeared to come primarily from Richmond. In fact, for those hired on or before 1948 at the Richmond refinery, the SMR for other lymphatic tissue cancer was 185.8, significant at the 0.05 level.

Special Analysis for Lymphatic and Hematopoietic Cancer

Based on results from previous studies cited, lymphatic and hematopoietic cancer was an area of concern in this study of refinery workers. As such, this cause of death, as well as the sub-category, leukemia, were examined in greater detail. Table 26 shows the mortality from all lymphopoietic cancer, which includes all lymphatic cancer and leukemias, by latency and length of employment. Although total lymphopoietic cancer had an SMR of only 105.0 (not significant), analysis by duration of employment and latency (time since first employment) shows some upward SMR trend, by both variables, albeit with small numbers in the short-term categories. For leukemia, a sub-group of the lympho-

poietic category, Table 27 shows a somewhat similar trend, but with even smaller numbers in the short-term categories for either latency or duration.

Special Analysis for Malignant, Benign and "Nature Unspecified" Brain Tumors

The petrochemical industry has had considerable interest in brain tumors and, specifically, brain cancer, following the publication of several studies which found elevated risk [Thomas et al 1982, Theriault and Goulet 1979, Alexander et al 1980, Waxweiler et al 1983, Wen et al 1981]. Frequently, brain cancers are incompletely certified, and lack histologic diagnosis. To overcome this under-reporting of malignant brain tumors, and to recognize the lethality of benign brain tumors, some investigators (e.g., NIOSH) have combined benign and "nature unspecified" brain tumors with brain cancer as a category straddling three ICD divisions.

Table 28 presents an analysis of all brain tumors (classified as malignant, benign or unspecified) among males. National age-race-sex-specific death rates for benign brain tumors (8th ICD 225.0) are not published, but were obtained for this analysis by special request to the National Center for Health Statistics (NCHS). In calculating the expected deaths for benign brain tumors, the 1968 U.S. death rates were used. Prior to 1968, no separate rates were generated for benign brain tumors. In addition, SMRs for brain tumors, nature unspecified (8th ICD 239) are also presented in the table. Although there was a slight non-significant excess in malignant cancer of the brain and central nervous system, deficits were observed for benign and unspecified brain tumors. When all three categories were combined, the observed number of deaths (23) was identical to the expected (23.0).

DISCUSSION

The cohort consisted of a total of 14,179 Chevron employees from the Richmond and El Segundo refineries. As of 12/31/1980, 78.83% of the cohort were still alive, 16.16% identified as deceased, and 5.01% lost to follow-up. This magnitude of cohort members with unknown vital status is commonly observed in epidemiologic studies of this kind.

The total cohort was relatively large, so it was quite adequate for examining mortality from a number of individual causes. Although the Richmond and El Segundo refineries had a few minor differences in cause-specific mortality, their experience was sufficiently similar to justify combining them in the analysis in order to increase statistical power (in analyzing less common causes of death).

The all causes SMR was only 72.4, a highly significant reduction from that expected on the basis of U.S. national statistics, and somewhat lower than that often found in cohorts demonstrating the "healthy worker effect". Comparison of the U.S. and the local county cancer statistics indicates that similar results would have been obtained had we compared our cohort against county rates. We see no methodologic flaw that might produce this low SMR; we therefore conclude that this cohort has an unusually low mortality rate. Presumably, this is a combination of the usual healthy worker effect (selection of the healthy for employment), a relative absence of serious risk from the job, and the effects of continuing employment with its several benefits.

The total cohort experienced 869 fewer deaths than expected from all causes. Some of the larger deficits, by cause, were as follows:

◦ Cancer of digestive system	50 fewer deaths than expected
◦ Cancer of respiratory system	61 fewer deaths than expected
◦ Allergic, metabolic and endocrine disease	31 fewer deaths than expected
◦ Diseases of circulatory system	440 fewer deaths than expected
◦ All respiratory diseases (non-neoplastic)	64 fewer deaths than expected
◦ All accidents	59 fewer deaths than expected

These six categories, which represent most of the mortality deficit, probably all reflect a combination of initial selection and lifestyle. Within the latter factor, the reduced frequency of smoking would reduce mortality from respiratory and digestive cancer, diseases of the circulatory system, and all respiratory disease.

In our analyses, the U.S. national mortality experience was used in calculating the expected deaths for comparison. To put the refineries and the study use of national mortality statistics into perspective, Table 29 was created. The age-adjusted mortality rates for the cancers of interest show little variation between either of the counties where the two refineries are located and the U.S. rates. Therefore, it appears unlikely that regional mortality difference had any measurable effect on the results.

Because of the essentially negative findings, we calculated the power of the study as it concerned certain diagnoses of interest. Table 30 displays the results previously reported by others, and the minimum relative risk that was detectable with 80% certainty in this study. The 80% is a conventional level for examining the statistical power. For most malignant causes of death that have been implicated in previous studies of refinery workers, the cohort as a whole was sufficiently large to detect with reasonable certainty any significant excess risk greater than 2-fold.

The petroleum industry, especially in Texas, has had considerable interest in brain tumors and brain cancer. To overcome the frequent under-reporting of malignant brain tumors, and to recognize the lethality of benign brain tumors, we have combined benign and "nature unspecified" brain tumors with brain cancer as a category straddling three ICD divisions (Table 28). Our analysis indicates that there was a slight (non-significant) excess in malignant brain cancer (primarily from Richmond), but a deficit in the other two categories, particularly in the category of brain tumors, nature unspecified. For the three categories as a whole, the observed mortality was exactly as expected. One possible explanation for this observation is that diagnostic practice and death certification for brain cancer in Richmond and El Segundo, both within large metropolitan areas (San Francisco and Los Angeles, respectively), are more specific and complete than the nation as a whole. A previous study [Greenwald, 1981] has indicated that among the medically well-insured, a high level of investigation may lead to an increased frequency of the diagnosis of brain cancer, giving an apparent (not real) increase in reported incidence rates. However, within the Chevron cohort, other explanations cannot be ruled out.

For malignancies of the lymphopoietic (lymphatic and hematopoietic) system, there was a slight, non-significant excess (the study had 80% power to exclude only an SMR of 150 or higher). Furthermore, there was a trend of increasing SMRs with both increasing duration of employment and latency since first employment. This pattern was compatible with an exposure-related disease, although numbers were too small (within each time interval) to be conclusive of a trend.

When the sub-categories within all lymphopoietic cancer were examined, it was found that the excess came primarily from lymphosarcoma and reticulosarcoma, as well as other lymphatic tissue cancer. There was a deficit in Hodgkin's disease (SMR = 52.1, not significant), but the number was small. For leukemia, there was a slight non-significant deficit (SMR = 88.3, not significant). As previously noted, Richmond and El Segundo refineries differed somewhat, with Richmond having a significant excess in other lymphatic cancer for persons hired before 1948. Although leukemia had an elevated SMR for both refineries among pre-1949 hirees, no cases occurred at either refinery in those workers hired after 1948.

Between refineries, there was some difference in total lymphopoietic cancer experience, with Richmond showing an excess (SMR = 118, not significant) and El Segundo a deficit (SMR = 82, not significant). The difference in the two refineries was not significant.

Among the work location sub-cohorts, there were no major differences in mortality patterns. Maintenance workers had less of an excess of lymphopoietic cancer than did laboratory or operating personnel. The latter was the only cohort with an excess of leukemia.

We suggest caution in interpreting mortality patterns, by diagnosis, within the category of lymphatic and hematopoietic cancer (ICD 200-209). With the possible exception of Hodgkin's disease of recent diagnosis, there is considerable opportunity for misdiagnosis, misclassification, and even multiple diagnoses among the other rubrics in the category. For instance, both lymphosarcomas and myeloproliferative syndromes frequently terminate in acute myelocytic leukemias.

Furthermore, it has been suggested that most lymphatic and hematopoietic malignancy reflects an oncogenic insult to the precursor stem cell series [Bakhshi et al 1983 and Kersey 1983].

Because only first and last job were coded, it is difficult to draw firm conclusions concerning the effect (if any) of subcohort membership on a particular disease category of interest, such as the lymphatic and hematopoietic cancer. The split into subcohorts is most useful in examining general patterns only. A more accurate definition of subcohort risk for specific diagnoses will require further analysis of complete work histories.

Overall, the study has provided considerable reassurance concerning the long-term health of Chevron refinery employees. Total mortality was low, and there was no suspicion of excess risk for either lung cancer (an important issue in both Contra Costa and Los Angeles counties) or kidney and digestive cancer (previously reported in refinery workers). For cancers of the lymphopoietic system, the study is more equivocal. Although no statistically significant increases in lymphopoietic cancer were observed, the results have raised questions concerning the potential risk to subcohorts or specific exposure categories. While the excess risk appears confined to lymphatic cancer, not leukemia, among persons at Richmond hired in or prior to 1948, a detailed follow-up study will be necessary to identify any association between this disease category and any specific job or work location.

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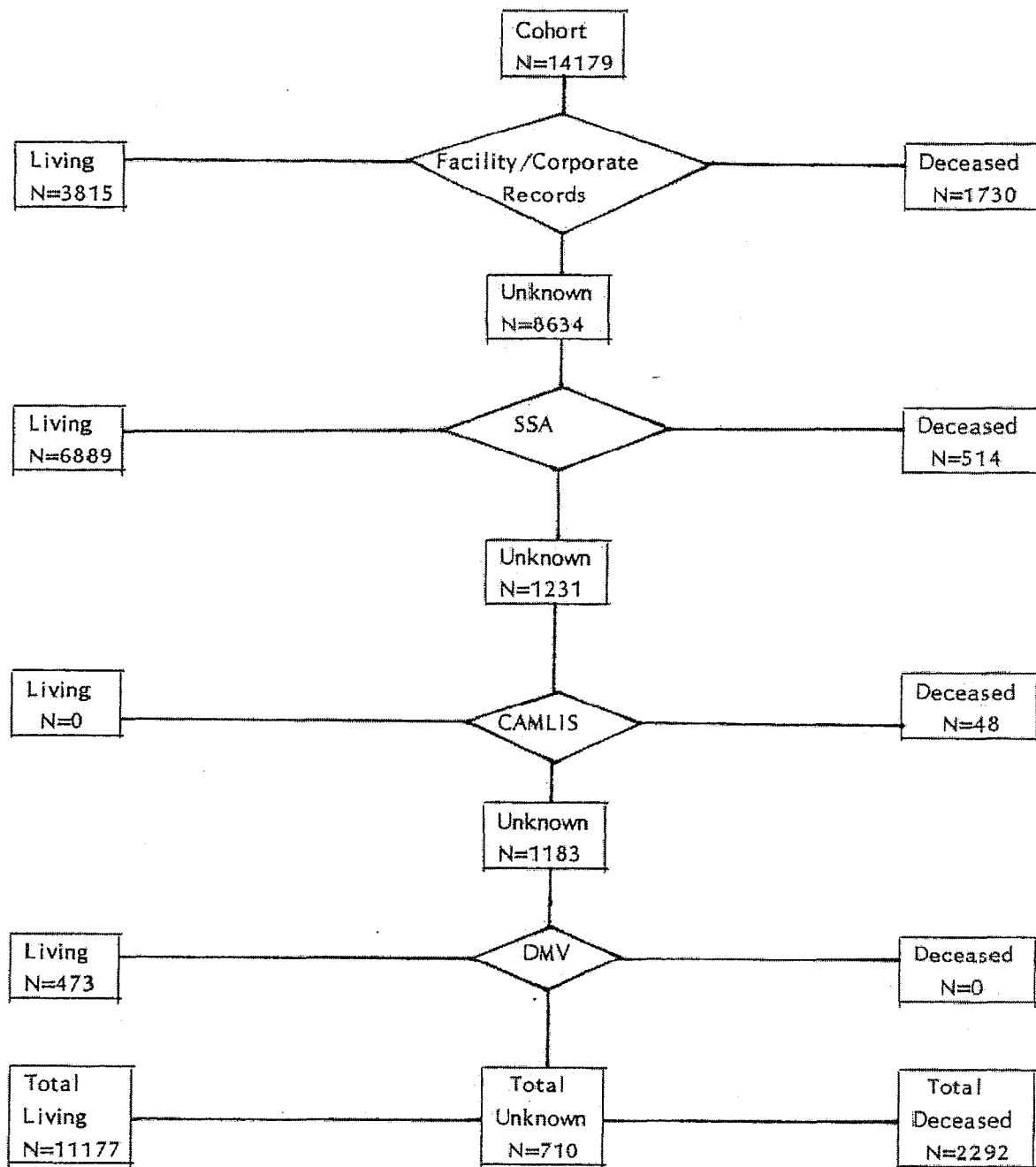
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FIGURE 1

Summary of Vital Status Follow-up for all Cohort Members



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 RICHMOND & PLEASANT

TABLE 1

Summary of Site-Specific Cancer Excess from Previous
 Studies of Refinery Workers

Cancer Site	Tabershaw/ Cooper 1974	Theriault/ Goulet 1979	Hanis et al 1979	Thomas et al 1982	Rushton/ Alderson 1981 a&b	Hanis et al 1982	Schottenfeld et al 1981	Wen et al 1981
Nasal cavities					S			
Lung (respiratory)	D		S,D					
Esophagus			S,D		S,D			
Stomach (digestive)		E	S,D	S	S,D			
Intestines			S		S			
Rectum					S,D		E	
Pancreas						E		
Lymphoma	D			S				
Leukemia				S	S		S	
Multiple myeloma				S			S	
Lymphopoietic (NOS)					S	E		
Brain (CNS)		S		S		E	E	E
Genital (NOS)	D							
Kidney						E		
Testes						E		
Melanoma (skin)					S		S	

D = Dose-Related

S = Significant Excess

E = Excess (not statistically significant), but regarded as important by the authors.

TABLE 2

Distribution by Sex and Race of All Cohort Members
at Richmond and El Segundo Refineries

Race	Male	Female	Total
White	10,127	508	10,635
Non-White	718	54	772
Unknown	2,656	116	2,772
Total	13,501	678	14,179

TABLE 3

Birth Year Distribution for All Cohort Members
at Richmond and El Segundo Refineries

Year of Birth	Frequency	Percent
1870-74	1	0.007
1880-84	2	0.014
1885-89	248	1.749
1890-94	393	2.772
1895-99	488	3.442
1900-04	506	3.569
1905-09	701	4.944
1910-14	951	6.707
1915-19	1196	8.435
1920-24	1595	11.249
1925-29	1406	9.916
1930-34	1300	9.168
1935-39	1331	9.387
1940-44	1280	9.027
1945-49	1326	9.352
1950-54	1014	7.151
1955-59	406	2.863
1960-64	35	0.247
TOTAL	14179	100.000

TABLE 4

Distribution of Year of Hire of all Cohort Members
at Richmond and El Segundo Refineries

Year of Hire	<u>Richmond</u>		<u>El Segundo</u>		<u>Both Refineries</u>	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
<1920	258	2.88	65	1.25	323	2.28
1920-24	229	2.55	133	2.56	362	2.55
1925-29	137	1.53	115	2.21	252	1.78
1930-34	91	1.01	77	1.48	168	1.18
1935-39	356	3.96	167	3.21	523	3.69
1940-44	750	8.35	439	8.45	1189	8.39
1945-49	1788	19.91	837	16.10	2625	18.51
1950-54	984	10.96	631	12.14	1615	11.39
1955-59	946	10.53	523	10.06	1469	10.36
1960-64	762	8.48	375	7.21	1137	8.02
1965-69	847	9.43	517	9.95	1364	9.62
1970-74	861	9.59	671	12.91	1532	10.80
1975-79	972	10.82	648	12.47	1620	11.43
TOTAL	8981	100.00	5198	100.00	14179	100.00

TABLE 5

Distribution of Age at Hire of All Cohort Members
at Richmond and El Segundo Refineries

Age at Hire	Frequency	Percent
<20	1608	11.341
20-24	4847	34.184
25-29	3517	24.804
30-34	1904	13.428
35-39	1018	7.180
40-44	600	4.232
45-49	395	2.786
50-54	201	1.418
55-59	75	0.529
60-64	13	0.092
70-74	1	0.007
TOTAL	14179	100.00

TABLE 6

Distribution by Year of Termination or Transfer for Terminated and Transferred Cohort Members at the Richmond and El Segundo Refineries

Year of Transfer or Termination	Frequency	Percent
1950-54	1204	16.95
1955-59	1094	15.40
1960-64	1321	18.59
1965-69	1289	18.14
1970-74	851	11.98
1975-80	1346	18.94
TOTAL	7105	100.00

TABLE 7

Distribution by Employment Status of All Cohort Members
at Richmond and El Segundo Refineries

Employment Status	Frequency	Percent
Active	3465	24.44
Retired	3144	22.18
Normal	(2814)	(19.85)
Disabled	(330)	(2.33)
Terminated	5979	42.17
Normal	(5677)	(40.04)
Health-related	(302)	(2.13)
Died Employed	465	3.28
Transferred	1126	7.94
Within Study	(142)	(1.00)
Out of Study	(984)	(6.94)
TOTAL	14179	100.00

TABLE 8

Distribution by Length of Employment of all Cohort Members
Richmond and El Segundo Refineries

Employment Length (in years)	Frequency	Percent
<5	4753	33.52
5-9	2752	19.41
10-14	1417	9.99
15-19	823	5.80
20-24	837	5.90
25-29	1194	8.42
30-34	1292	9.11
35-39	724	5.11
40+	387	2.73
TOTAL	14179	100.00

TABLE 9

Distribution by Vital Status (as of 31 December 1980) of All Cohort Members

Vital Status	Frequency	Percent	Death Certificates	
			Obtained	Outstanding
Alive	11177	78.83		
Active	(3465)	(24.44)		
Retired	(1987)	(14.01)		
Terminated	(4717)	(33.27)		
Transferred	(1008)	(7.11)		
Dead	2292	16.16		
While employed	(465)	(3.28)	459	6
Retired	(1153)	(8.13)	1149	4
Terminated	(595)	(4.20)	634	40
Transferred	(79)	(0.55)		
Unknown	710	5.01		
Terminated	(667)	(4.70)		
Retired	(4)	(0.03)		
Transferred	(39)	(0.28)		
TOTAL	14179	100.00	2242 (97.82%)	50 (2.2%)

TABLE 10

Distribution by Year of Death of Deceased Cohort Members
at Richmond and El Segundo Refineries

Year of Death	Frequency	Percent
1950-54	128	5.585
1955-59	205	8.944
1960-64	297	12.958
1965-69	411	17.932
1970-74	492	21.466
1975-80	759	33.115
TOTAL	2292	100.000

TABLE 11

Distribution by Age at Death of Deceased Cohort Members
at Richmond and El Segundo Refineries

Age at Death	Frequency	Percent
20-24	21	0.916
25-29	31	1.353
30-34	43	1.876
35-39	56	2.443
40-44	90	3.927
45-49	158	6.894
50-54	203	8.857
55-59	253	11.038
60-64	308	13.438
65-69	325	14.180
70-74	308	13.438
75+	496	21.640
TOTAL	2292	100.000

TABLE 12

Observed and Expected Deaths by Cause,
SMRs and Their 95% Confidence Limits for
Total Cohort at the Richmond and El Segundo Refineries

No. of Persons = 14,179 Person-Years = 266470.7

Cause of Death (8th ICDA)	Obs. Deaths	Expected Deaths	SMR	Lower Limit	Upper Limit
All Causes	2292	3167.39	72.4†	69.4	75.4
Infective and Parasitic Diseases (000-139)	14	37.18	37.7†	20.6	63.2
All Cancers (140-209)	462	610.70	75.7†	68.9	82.9
Cancer of Buccal Cavity and Pharynx (140-149)	9	19.13	47.0*	21.6	89.3
Cancer of Digestive System (150-159)	125	174.62	71.6†	59.6	85.3
Cancer of Esophagus (150)	12	14.37	83.5	43.0	145.7
Cancer of Stomach (151)	26	34.10	76.2	49.8	111.8
Cancer of Large Intestine (153)	40	55.99	71.4*	51.0	97.3
Cancer of Rectum (154)	18	20.20	89.1	52.7	140.8
Cancer of Liver (155-156)	6	12.25	49.0	17.9	106.7
Cancer of Pancreas (157)	20	33.78	59.2*	36.1	91.5
Cancer of Respiratory System (160-163)	135	196.53	68.7†	57.6	81.4
Cancer of Larynx (161)	9	9.03	99.6	45.7	189.1
Cancer of Lung (162-163)	124	185.42	66.9†	55.6	79.8
Cancer of Skin (172-173)	10	10.81	92.5	44.5	170.1
Cancer of Breast (174)	3	2.95	101.8	21.0	297.8
Cancer of Prostate (185)	34	43.36	78.4	54.2	109.6
Cancer of Testis (186-187)	2	3.77	53.0	6.4	191.4
Cancer of Bladder (188)	12	19.23	62.4	32.2	108.9
Cancer of Kidney (189)	13	14.82	87.7	46.7	150.0
Cancer of Brain and CNS (191-192)	22	17.48	125.9	78.7	190.7
Lymphatic & Hematopoietic Cancer (200-209)	64	60.97	105.0	80.9	134.1
Lymphosarcoma and Reticulosarcoma (200)	17	13.43	126.6	73.6	202.6
Hodgkin's Disease (201)	4	7.68	52.1	14.2	133.1
Leukemia & Aleukemia (204-207)	22	24.92	88.3	55.2	133.8
Other Lymphatic Tissue Cancer (202, 203, 208)	20	14.12	141.6	86.4	218.9
Benign Neoplasms (210-239)	5	8.14	61.5	19.9	143.6
Diabetes Mellitus (250)	17	45.81	37.1†	21.6	59.4
Diseases of Blood (280-289)	6	7.04	85.2	31.2	185.6
Diseases of Nervous System (320-389)	12	25.21	47.6†	24.5	83.1
Diseases of Circulatory System (390-458)	1228	1667.74	73.6†	69.6	77.9
Chronic Rheumatic Heart Disease (393-398)	19	31.11	61.1*	36.8	95.4
Arteriosclerotic Heart Disease (410-413)	924	1165.83	79.3†	74.2	84.5
Vascular lesions of CNS (430-438)	158	237.41	66.6†	56.6	77.7
Nonmalignant Respiratory Disease (460-519)	105	188.66	55.7†	45.5	67.4
Pneumonia (480-486)	35	70.76	49.5†	34.3	68.8
Emphysema (492)	26	48.68	53.4†	34.9	78.3
Diseases of Digestive System (520-577)	97	149.90	64.7†	52.5	79.0
Cirrhosis of Liver (551)	60	75.91	79.0	60.3	101.7
Diseases of Genito-Urinary System (580-629)	22	44.16	49.8†	31.1	75.5
Senility & Ill-Defined Conditions (780-799)	10	36.82	27.2†	13.1	49.9
Accidents, Poisonings, & Violence (E800-E998)	243	306.74	79.2†	69.5	89.9
Accidents (800-949)	146	205.07	71.2†	60.1	83.8
Motor Vehicle Accidents (810-827)	74	96.05	77.0*	60.6	96.8
Suicide (950-959)	88	68.94	127.6*	102.6	157.2

*Significant at 0.05

†Significant at 0.01

TABLE 13

Observed and Expected Deaths by Cause,
SMRs and Their 95% Confidence Limits for
Total Cohort at the Richmond Refinery

No. of Persons = 8,981

Person-Years = 172459.8

Cause of Death (8th ICDA)	Obs. Deaths	Expected Deaths	SMR	Lower Limit	Upper Limit
All Causes	1507	2033.85	74.1†	70.4	77.9
Infective and Parasitic Diseases (000-139)	5	24.19	20.7†	6.7	48.3
All Cancers (140-209)	302	389.54	77.5†	69.0	86.8
Cancer of Buccal Cavity and Pharynx (140-149)	7	12.23	57.2	23.0	118.0
Cancer of Digestive System (150-159)	85	111.87	76.0†	60.8	94.0
Cancer of Esophagus (150)	8	9.26	86.4	37.3	170.1
Cancer of Stomach (151)	21	22.03	95.3	58.8	145.8
Cancer of Large Intestine (153)	27	35.68	75.7	49.8	110.1
Cancer of Rectum (154)	13	12.93	100.5	53.5	171.8
Cancer of Liver (155-156)	2	7.89	25.4*	3.1	91.6
Cancer of Pancreas (157)	13	21.57	60.3	32.1	103.0
Cancer of Respiratory System (160-163)	82	124.99	65.6†	52.2	81.5
Cancer of Larynx (161)	6	5.77	104.0	38.1	226.6
Cancer of Lung (162-163)	74	117.89	62.8†	49.3	78.9
Cancer of Skin (172-173)	7	6.91	101.2	40.7	208.8
Cancer of Breast (174)	2	1.57	127.2	15.4	459.1
Cancer of Prostate (185)	23	27.84	82.6	52.3	124.0
Cancer of Testis (186-187)	2	2.47	81.1	9.8	292.8
Cancer of Bladder (188)	10	12.25	81.6	39.2	150.0
Cancer of Kidney (189)	9	9.45	95.2	43.7	180.7
Cancer of Brain and CNS (191-192)	15	11.16	134.5	75.1	221.9
Lymphatic & Hematopoietic Cancer (200-209)	46	38.99	118.0	86.4	157.5
Lymphosarcoma and Reticulosarcoma (200)	13	8.59	151.3	80.5	258.6
Hodgkin's Disease (201)	3	4.97	60.4	12.5	176.6
Leukemia & Aleukemia (204-207)	14	15.94	87.8	48.0	147.4
Other Lymphatic Tissue Cancer (202, 203, 208)	15	8.98	167.0	93.3	275.6
Benign Neoplasms (210-239)	2	5.21	38.4	4.6	138.6
Diabetes Mellitus (250)	12	29.44	40.8†	21.0	71.1
Diseases of Blood (280-289)	4	4.53	88.2	24.0	225.7
Diseases of Nervous System (320-389)	10	16.19	61.8	29.7	113.6
Diseases of Circulatory System (390-458)	801	1069.96	74.9†	69.8	80.2
Chronic Rheumatic Heart Disease (393-398)	8	19.93	40.1†	17.3	79.0
Arteriosclerotic Heart Disease (410-413)	605	745.52	81.2†	74.8	87.9
Vascular lesions of CNS (430-438)	105	153.27	68.5†	56.0	83.0
Nonmalignant Respiratory Disease (460-519)	71	120.33	59.0†	46.2	74.5
Pneumonia (480-486)	21	45.53	46.1†	28.5	70.5
Emphysema (492)	17	30.84	55.1†	32.0	88.2
Diseases of Digestive System (520-577)	68	96.15	70.7†	55.0	89.7
Cirrhosis of Liver (551)	41	48.58	84.4	60.5	114.6
Diseases of Genito-Urinary System (580-629)	15	28.69	52.3†	29.2	86.3
Senility & Ill-Defined Conditions (780-799)	7	23.91	29.3†	11.8	60.4
Accidents, Poisonings, & Violence (E800-E998)	162	200.25	80.9†	68.9	94.3
Accidents (800-949)	99	134.02	73.9†	60.0	90.0
Motor Vehicle Accidents (810-827)	51	63.10	80.8	60.1	106.4
Suicide (950-959)	56	44.39	126.2	95.1	164.0

*Significant at 0.05

†Significant at 0.01

TABLE 14

Observed and Expected Deaths by Cause,
SMRs and Their 95% Confidence Limits for
Total Cohort at El Segundo Refinery

No. of Persons = 5,198 Person-Years = 94008.1

Cause of Death (8th ICDA)	Obs. Deaths	Expected Deaths	SMR	Lower Limit	Upper Limit
All Causes	785	1133.75	69.2†	64.5	74.3
Infective and Parasitic Diseases (000-139)	9	12.99	69.3	31.8	131.4
All Cancers (140-209)	160	221.15	72.3†	61.6	84.4
Cancer of Buccal Cavity and Pharynx (140-149)	2	6.90	29.0	3.5	104.6
Cancer of Digestive System (150-159)	40	62.75	63.7†	45.5	86.8
Cancer of Esophagus (150)	4	5.12	78.1	21.3	199.8
Cancer of Stomach (151)	5	12.07	41.4*	13.4	96.8
Cancer of Large Intestine (153)	13	20.30	64.0	34.1	109.5
Cancer of Rectum (154)	5	7.27	68.8	22.3	160.7
Cancer of Liver (155-156)	4	4.36	91.7	25.0	234.5
Cancer of Pancreas (157)	7	12.21	57.3	23.0	118.2
Cancer of Respiratory System (160-163)	53	71.55	74.1*	55.4	97.0
Cancer of Larynx (161)	3	3.26	91.9	18.9	268.7
Cancer of Lung (162-163)	50	67.54	74.0*	54.8	97.7
Cancer of Skin (172-173)	3	3.89	77.1	15.9	225.4
Cancer of Breast (174)	1	1.37	72.8	1.8	404.7
Cancer of Prostate (185)	11	15.52	70.9	35.4	126.8
Cancer of Testis (186-187)	0	1.31	-	-	-
Cancer of Bladder (188)	2	6.98	28.7	3.5	103.5
Cancer of Kidney (189)	4	5.37	74.5	20.3	190.5
Cancer of Brain and CNS (191-192)	7	6.32	110.7	44.5	228.3
Lymphatic & Hematopoietic Cancer (200-209)	18	21.98	81.9	48.5	129.4
Lymphosarcoma and Reticulosarcoma (200)	4	4.83	82.8	22.6	211.7
Hodgkin's Disease (201)	1	2.72	36.8	0.9	204.4
Leukemia & Aleukemia (204-207)	8	8.98	89.1	38.4	175.4
Other Lymphatic Tissue Cancer (202,203,208)	5	5.14	97.3	31.5	227.3
Benign Neoplasms (210-239)	3	2.93	102.5	21.1	299.7
Diabetes Mellitus (250)	5	16.37	30.5†	9.9	71.3
Diseases of Blood (280-289)	2	2.51	79.7	9.7	287.8
Diseases of Nervous System (320-389)	2	9.03	22.2*	2.7	80.0
Diseases of Circulatory System (390-458)	427	597.77	71.4†	64.8	78.5
Chronic Rheumatic Heart Disease (393-398)	11	11.18	98.4	49.2	176.0
Arteriosclerotic Heart Disease (410-413)	319	420.30	75.9†	67.8	84.7
Vascular lesions of CNS (430-438)	53	84.15	63.0†	47.1	82.5
Nonmalignant Respiratory Disease (460-519)	34	68.34	49.8†	34.4	69.6
Pneumonia (480-486)	14	25.23	55.5*	30.3	93.1
Emphysema (492)	9	17.84	50.5*	23.1	95.7
Diseases of Digestive System (520-577)	29	53.75	54.0†	36.2	77.5
Cirrhosis of Liver (551)	19	27.33	69.5	41.9	108.6
Diseases of Genito-Urinary System (580-629)	7	15.47	45.3*	18.2	93.3
Senility & Ill-Defined Conditions (780-799)	3	12.91	23.2†	4.8	67.9
Accidents, Poisonings, & Violence (E800-E998)	81	106.49	76.1*	60.5	94.6
Accidents (800-949)	47	71.07	66.1†	48.6	88.0
Motor Vehicle Accidents (810-827)	23	32.95	69.8	44.2	104.8
Suicide (950-959)	32	24.55	130.3	89.0	184.2

*Significant at 0.05

†Significant at 0.01

TABLE 15

Observed and Expected Deaths by Cause,
SMRs and Their 95% Confidence Limits for
White Males at the Richmond and El Segundo Refineries

No. of Persons = 12,783 Person-Years = 251983.4

Cause of Death (8th ICDA)	Obs. Deaths	Expected Deaths	SMR	Lower Limit	Upper Limit
All Causes	2218	3054.94	72.6†	69.6	75.7
Infective and Parasitic Diseases (000-139)	12	35.19	34.1†	17.6	59.5
All Cancers (140-209)	443	588.29	75.3†	68.5	82.6
Cancer of Buccal Cavity and Pharynx (140-149)	9	18.60	48.4*	22.2	91.8
Cancer of Digestive System (150-159)	120	168.41	71.3†	59.1	85.2
Cancer of Esophagus (150)	11	13.72	80.2	40.1	143.4
Cancer of Stomach (151)	26	32.84	79.2	51.7	116.1
Cancer of Large Intestine (153)	36	54.00	66.7*	46.6	92.3
Cancer of Rectum (154)	18	19.65	91.6	54.2	144.7
Cancer of Liver (155-156)	6	11.70	51.3	18.8	111.8
Cancer of Pancreas (157)	20	32.72	61.1*	37.3	94.5
Cancer of Respiratory System (160-163)	131	192.35	68.1†	46.9	80.9
Cancer of Larynx (161)	9	8.83	101.9	46.7	193.3
Cancer of Lung (162-163)	120	181.50	66.1†	54.8	79.1
Cancer of Skin (172-173)	9	10.56	85.3	39.1	161.8
Cancer of Prostate (185)	33	42.25	78.1	53.6	109.8
Cancer of Testis (186-187)	2	3.72	53.8	6.5	194.1
Cancer of Bladder (188)	12	18.89	63.5	32.7	110.9
Cancer of Kidney (189)	12	14.47	82.9	42.7	144.7
Cancer of Brain and CNS (191-192)	21	16.99	123.6	76.3	189.0
Lymphatic & Hematopoietic Cancer (200-209)	63	59.07	106.7	82.0	136.5
Lymphosarcoma and Reticulosarcoma (200)	17	13.05	130.3	75.7	208.4
Hodgkin's Disease (201)	4	7.46	53.6	14.6	137.1
Leukemia & Aleukemia (204-207)	21	24.17	86.9	53.6	132.8
Other Lymphatic Tissue Cancer (202,203,208)	20	13.59	147.1	89.7	227.4
Benign Neoplasms (210-239)	5	7.79	64.2	20.8	150.0
Diabetes Mellitus (250)	16	43.63	36.7†	21.0	59.5
Diseases of Blood (280-289)	6	6.65	90.2	33.0	196.5
Diseases of Nervous System (320-389)	12	24.02	50.00*	25.8	87.2
Diseases of Circulatory System (390-458)	1201	1621.46	74.1†	69.9	78.4
Chronic Rheumatic Heart Disease (393-398)	19	29.88	63.6*	38.3	99.4
Arteriosclerotic Heart Disease (410-413)	902	1141.07	79.0†	74.0	84.4
Vascular lesions of CNS (430-438)	157	227.17	69.1†	58.7	80.8
Nonmalignant Respiratory Disease (460-519)	102	183.28	55.7†	45.3	67.6
Pneumonia (480-486)	35	67.90	51.5†	35.8	71.7
Emphysema (492)	25	48.08	52.0†	33.5	76.7
Diseases of Digestive System (520-577)	92	143.98	63.9†	51.6	78.3
Cirrhosis of Liver (551)	57	72.66	78.5	59.3	101.7
Diseases of Genito-Urinary System (580-629)	20	41.87	47.8†	29.1	73.8
Senility & Ill-Defined Conditions (780-799)	10	34.00	29.4†	14.1	54.1
Accidents, Poisonings, & Violence (E800-E998)	232	288.13	80.5†	70.4	91.6
Accidents (800-949)	141	196.01	71.9†	60.5	84.9
Motor Vehicle Accidents (810-827)	70	91.88	76.2*	59.5	96.3
Suicide (950-959)	83	67.05	123.8	98.7	153.5

*Significant at 0.05

†Significant at 0.01

TABLE 16

Observed and Expected Deaths by Cause,
SMRs and Their 95% Confidence Limits for
White Females at the Richmond and El Segundo Refineries

No. of Persons = 624 Person-Years = 7953.2

Cause of Death (8th ICDA)	Obs. Deaths	Expected Deaths	SMR	Lower Limit	Upper Limit
All Causes	41	44.25	92.7	66.5	125.8
Infective and Parasitic Diseases (000-139)	0	0.44	-	-	-
All Cancers (140-209)	15	12.58	119.2	66.6	196.7
Cancer of Buccal Cavity and Pharynx (140-149)	0	0.17	-	-	-
Cancer of Digestive System (150-159)	5	3.09	161.9	52.4	378.3
Cancer of Esophagus (150)	1	0.10	994.0	25.1	5522.3
Cancer of Stomach (151)	0	0.41	-	-	-
Cancer of Large Intestine (153)	4	1.35	296.7	80.8	758.9
Cancer of Rectum (154)	0	0.32	-	-	-
Cancer of Liver (155-156)	0	0.28	-	-	-
Cancer of Pancreas (157)	0	0.54	-	-	-
Cancer of Respiratory System (160-163)	3	1.30	231.2	47.7	676.2
Cancer of Larynx (161)	0	0.03	-	-	-
Cancer of Lung (162-163)	3	1.24	242.2	49.9	708.1
Cancer of Skin (172-173)	1	0.19	534.6	13.5	2969.7
Cancer of Breast (174)	2	2.92	68.5	8.3	247.5
Cancer of Bladder (188)	0	0.14	-	-	-
Cancer of Kidney (189)	1	0.19	526.2	13.3	2923.2
Cancer of Brain and CNS (191-192)	1	0.35	287.2	7.3	1595.7
Lymphatic & Hematopoietic Cancer (200-209)	0	1.09	-	-	-
Lymphosarcoma and Reticulosarcoma (200)	0	0.25	-	-	-
Hodgkin's Disease (201)	0	0.13	-	-	-
Leukemia & Aleukemia (204-207)	0	0.42	-	-	-
Other Lymphatic Tissue Cancer (202,203,208)	0	0.28	-	-	-
Benign Neoplasms (210-239)	0	0.21	-	-	-
Diabetes Mellitus (250)	1	1.17	85.6	2.2	475.6
Diseases of Blood (280-289)	0	0.15	-	-	-
Diseases of Nervous System (320-389)	0	0.51	-	-	-
Diseases of Circulatory System (390-458)	13	20.06	64.8	34.5	110.8
Chronic Rheumatic Heart Disease (393-398)	0	0.82	-	-	-
Arteriosclerotic Heart Disease (410-413)	12	11.60	103.5	53.3	180.6
Vascular lesions of CNS (430-438)	1	4.41	22.7	0.6	125.9
Nonmalignant Respiratory Disease (460-519)	1	1.85	54.0	1.4	300.3
Pneumonia (480-486)	0	0.86	-	-	-
Emphysema (492)	1	0.25	402.7	10.2	2237.4
Diseases of Digestive System (520-577)	1	2.12	47.2	1.2	262.5
Cirrhosis of Liver (551)	1	1.04	95.8	2.4	532.4
Diseases of Genito-Urinary System (580-629)	1	0.69	144.4	3.7	802.0
Senility & Ill-Defined Conditions (780-799)	0	0.46	-	-	-
Accidents, Poisonings, & Violence (E800-E998)	5	3.01	166.3	53.8	388.5
Accidents (800-949)	1	1.89	52.9	1.3	293.7
Motor Vehicle Accidents (810-827)	1	0.96	104.1	2.6	578.4
Suicide (950-959)	4	0.81	491.0*	133.8	1255.9

*Significant at 0.05

†Significant at 0.01

TABLE 17

Observed and Expected Deaths by Cause,
SMRs and Their 95% Confidence Limits for
Non-White Males at the Richmond and El Segundo Refineries

No. of Persons = 718 Person-Years = 6,252.0

Cause of Death (8th ICDA)	Obs. Deaths	Expected Deaths	SMR	Lower Limit	Upper Limit
All Causes	33	67.71	48.7†	33.5	68.5
Infective and Parasitic Diseases (000-139)	2	1.53	130.5	15.8	471.1
All Cancers (140-209)	4	9.72	41.1	11.2	105.2
Cancer of Buccal Cavity and Pharynx (140-149)	0	0.36	-	-	-
Cancer of Digestive System (150-159)	0	3.10	-	-	-
Cancer of Esophagus (150)	0	0.55	-	-	-
Cancer of Stomach (151)	0	0.84	-	-	-
Cancer of Large Intestine (153)	0	0.64	-	-	-
Cancer of Rectum (154)	0	0.23	-	-	-
Cancer of Liver (155-156)	0	0.27	-	-	-
Cancer of Pancreas (157)	0	0.52	-	-	-
Cancer of Respiratory System (160-163)	1	2.89	34.6	0.9	192.4
Cancer of Larynx (161)	0	0.17	-	-	-
Cancer of Lung (162-163)	1	2.69	37.2	0.9	206.9
Cancer of Skin (172-173)	0	0.06	-	-	-
Cancer of Prostate (185)	1	1.10	90.7	2.3	503.8
Cancer of Testis (186-187)	0	0.05	-	-	-
Cancer of Bladder (188)	0	0.20	-	-	-
Cancer of Kidney (189)	0	0.16	-	-	-
Cancer of Brain and CNS (191-192)	0	0.14	-	-	-
Lymphatic & Hematopoietic Cancer (200-209)	1	0.79	125.8	3.2	698.8
Lymphosarcoma and Reticulosarcoma (200)	0	0.13	-	-	-
Hodgkin's Disease (201)	0	0.09	-	-	-
Leukemia & Aleukemia (204-207)	1	0.32	313.6	7.9	1742.4
Other Lymphatic Tissue Cancer (202,203,208)	0	0.25	-	-	-
Benign Neoplasms (210-239)	0	0.13	-	-	-
Diabetes Mellitus (250)	0	1.00	-	-	-
Diseases of Blood (280-289)	0	0.23	-	-	-
Diseases of Nervous System (320-389)	0	0.68	-	-	-
Diseases of Circulatory System (390-458)	14	26.05	53.8*	29.4	90.2
Chronic Rheumatic Heart Disease (393-398)	0	0.41	-	-	-
Arteriosclerotic Heart Disease (410-413)	10	13.10	76.3	36.7	140.3
Vascular lesions of CNS (430-438)	0	5.79	-	-	-
Nonmalignant Respiratory Disease (460-519)	2	3.50	57.1	5.9	206.0
Pneumonia (480-486)	0	1.98	-	-	-
Emphysema (492)	0	0.35	-	-	-
Diseases of Digestive System (520-577)	4	3.74	106.9	29.1	273.3
Cirrhosis of Liver (551)	2	2.17	92.2	11.2	332.8
Diseases of Genito-Urinary System (580-629)	1	1.57	63.7	1.6	353.7
Senility & Ill-Defined Conditions (780-799)	0	2.33	-	-	-
Accidents, Poisonings, & Violence (E800-E998)	6	15.46	38.8*	14.2	84.5
Accidents (800-949)	4	7.13	56.1	15.3	143.6
Motor Vehicle Accidents (810-827)	3	3.18	94.3	19.4	275.8
Suicide (950-959)	1	1.06	94.3	2.4	524.1

*Significant at 0.05

†Significant at 0.01

TABLE 18

Observed Deaths by Cause and SMRs for
all Cohort Members in Laboratory Locations
at Richmond and El Segundo Refineries

Cause of Death (8th ICDA)	Richmond		El Segundo		Total Cohort	
	Obs.	SMR	Obs.	SMR	Obs.	SMR
All Causes	87	81.0*	47	64.0†	134	74.1†
Infective and Parasitic Diseases (000-139)	0	-	0	-	0	-
All Cancers (140-209)	18	87.0	11	74.2	29	81.7
Cancer of Buccal Cavity and Pharynx (140-149)	0	-	0	-	0	-
Cancer of Digestive System (150-159)	6	104.4	1	24.5	7	71.2
Cancer of Esophagus (150)	0	-	0	-	0	-
Cancer of Stomach (151)	0	-	0	-	0	-
Cancer of Large Intestine (153)	2	108.3	0	-	2	63.2
Cancer of Rectum (154)	3	456.2	1	215.2	4	356.4
Cancer of Liver (155-156)	0	-	0	-	0	-
Cancer of Pancreas (157)	1	88.5	0	-	1	51.2
Cancer of Respiratory System (160-163)	1	14.7*	2	38.8	3	25.1†
Cancer of Larynx (161)	0	-	0	-	0	-
Cancer of Lung (162-163)	1	15.6*	2	41.1	3	26.6†
Cancer of Skin (172-173)	1	249.1	1	377.3	2	300.1
Cancer of Breast (174)	0	-	0	-	0	-
Cancer of Prostate (185)	2	148.0	1	110.8	3	133.1
Cancer of Testis (186-187)	0	-	0	-	0	-
Cancer of Bladder (188)	0	-	1	229.0	1	95.4
Cancer of Kidney (189)	1	195.7	1	266.8	2	225.8
Cancer of Brain and CNS (191-192)	1	152.9	0	-	1	90.1
Lymphatic & Hematopoietic Cancer (200-209)	4	185.0	2	135.6	6	165.0
Lymphosarcoma and Reticulosarcoma (200)	1	210.4	1	303.7	2	248.6
Hodgkin's Disease (201)	0	-	0	-	0	-
Leukemia & Aleukemia (204-207)	1	115.1	0	-	1	68.8
Other Lymphatic Tissue Cancer (202,203,208)	2	412.0	1	282.4	3	357.4
Benign Neoplasms (210-239)	0	-	0	-	0	-
Diabetes Mellitus (250)	1	65.0	1	95.5	2	77.3
Diseases of Blood (280-289)	0	-	0	-	0	-
Diseases of Nervous System (320-389)	1	109.5	0	-	1	66.0
Diseases of Circulatory System (390-458)	45	82.5	26	68.5	71	76.8*
Chronic Rheumatic Heart Disease (393-398)	0	-	0	-	0	-
Arteriosclerotic Heart Disease (410-413)	36	93.5	21	76.6	57	86.5
Vascular lesions of CNS (430-438)	4	53.7	2	41.3	6	48.8
Nonmalignant Respiratory Disease (460-519)	2	32.5	3	69.1	5	47.6
Pneumonia (480-486)	0	-	1	66.8	1	26.3
Emphysema (492)	1	63.1	1	84.8	2	72.4
Diseases of Digestive System (520-577)	4	75.3	0	-	4	44.5
Cirrhosis of Liver (551)	3	106.3	0	-	3	62.4
Diseases of Genito-Urinary System (580-629)	1	68.5	0	-	1	42.1
Senility & Ill-Defined Conditions (780-799)	1	77.5	0	-	1	46.4
Accidents, Poisonings, & Violence (E800-E998)	12	97.6	5	70.6	17	87.7
Accidents (800-949)	5	59.8	2	42.2	7	53.4
Motor Vehicle Accidents (810-827)	0	-	1	45.5	1	15.9*
Suicide (950-959)	6	222.5	3	178.8	9	205.7

*Significant at 0.05

†Significant at 0.01

TABLE 19

Observed Deaths by Cause and SMRs for
all Cohort Members in Maintenance Locations
at Richmond and El Segundo Refineries

Cause of Death (8th ICDA)	Richmond		El Segundo		Total Cohort	
	Obs.	SMR	Obs.	SMR	Obs.	SMR
All Causes	849	74.0†	480	69.3†	1329	72.2†
Infective and Parasitic Diseases (000-139)	3	22.1†	9	114.5	12	56.0*
All Cancers (140-209)	165	75.0†	101	75.0†	266	75.0†
Cancer of Buccal Cavity and Pharynx (140-149)	3	43.2	1	23.6	4	35.8*
Cancer of Digestive System (150-159)	45	71.3*	25	64.9*	70	68.8†
Cancer of Esophagus (150)	5	94.1	2	63.3	7	82.6
Cancer of Stomach (151)	11	88.0	4	53.7	15	75.2
Cancer of Large Intestine (153)	11	54.9*	6	48.3	17	52.4†
Cancer of Rectum (154)	10	137.4	3	67.0	13	110.6
Cancer of Liver (155-156)	2	45.4	3	112.5	5	70.7
Cancer of Pancreas (157)	6	49.1	6	79.8	12	60.8
Cancer of Respiratory System (160-163)	44	61.5†	36	81.4	80	69.1†
Cancer of Larynx (161)	4	121.4	3	148.1	7	131.6
Cancer of Lung (162-163)	39	57.8†	33	79.1	72	65.9†
Cancer of Skin (172-173)	5	128.2	2	86.1	7	112.5
Cancer of Breast (174)	1	789.3	0	-	1	515.0
Cancer of Prostate (185)	13	80.6	7	70.9	20	76.9
Cancer of Testis (186-187)	2	143.8	0	-	2	93.1
Cancer of Bladder (188)	7	100.4	0	-	7	61.7
Cancer of Kidney (189)	6	112.1	1	30.3	7	80.9
Cancer of Brain and CNS (191-192)	9	143.8	5	133.4	14	139.9
Lymphatic & Hematopoietic Cancer (200-209)	26	118.6	10	75.3	36	102.3
Lymphosarcoma and Reticulosarcoma (200)	7	145.5	3	102.6	10	129.2
Hodgkin's Disease (201)	1	36.1	1	63.0	2	45.9
Leukemia & Aleukemia (204-207)	9	100.4	4	73.4	13	90.2
Other Lymphatic Tissue Cancer (202,203,208)	9	176.7	2	63.8	11	133.7
Benign Neoplasms (210-239)	1	34.5	1	57.4	2	43.1
Diabetes Mellitus (250)	4	24.3†	3	30.1*	7	26.5†
Diseases of Blood (280-289)	2	79.2	1	66.0	3	74.3
Diseases of Nervous System (320-389)	4	44.2	2	37.2	6	41.6*
Diseases of Circulatory System (390-458)	458	75.6†	261	70.4†	719	73.6†
Chronic Rheumatic Heart Disease (393-398)	3	27.3*	6	90.2	9	51.0*
Arteriosclerotic Heart Disease (410-413)	346	81.9†	195	74.6†	541	79.1†
Vascular lesions of CNS (430-438)	61	70.5†	32	61.3†	93	67.0†
Nonmalignant Respiratory Disease (460-519)	43	62.9†	18	42.4†	61	55.0†
Pneumonia (480-486)	13	50.4†	8	51.1	21	50.6†
Emphysema (492)	9	51.2*	3	26.7†	12	41.6†
Diseases of Digestive System (520-577)	40	73.9	18	55.5†	58	67.0†
Cirrhosis of Liver (551)	22	80.2	12	73.6	34	77.7
Diseases of Genito-Urinary System (580-629)	6	36.9†	5	52.9	11	42.8†
Senility & Ill-Defined Conditions (780-799)	4	29.4†	2	25.9*	6	28.1†
Accidents, Poisonings, & Violence (E800-E998)	90	81.2*	48	79.0	138	80.5†
Accidents (800-949)	57	76.5*	33	80.8	90	78.0*
Motor Vehicle Accidents (810-827)	29	83.2	12	64.5	41	76.7
Suicide (950-959)	29	117.2	15	105.6	44	113.0

*Significant at 0.05

†Significant at 0.01

TABLE 20

Observed Deaths by Cause and SMRs for
all Cohort Members in Operating Locations
at Richmond and El Segundo Refineries

Cause of Death (8th ICDA)	Richmond		El Segundo		Total Cohort	
	Obs.	SMR	Obs.	SMR	Obs.	SMR
All Causes	564	80.5†	253	77.4†	817	79.5†
Infective and Parasitic Diseases (000-139)	2	26.2*	0	-	2	18.2†
All Cancers (140-209)	116	86.2	47	74.6*	163	82.5*
Cancer of Buccal Cavity and Pharynx (140-149)	4	94.2	2	102.9	6	96.9
Cancer of Digestive System (150-159)	26	68.0*	10	55.0	36	63.8†
Cancer of Esophagus (150)	0	-	0	-	0	-
Cancer of Stomach (151)	8	108.3	2	57.1	10	91.8
Cancer of Large Intestine (153)	10	81.0	3	50.7	13	71.2
Cancer of Rectum (154)	3	67.9	2	94.8	5	76.6
Cancer of Liver (155-156)	1	38.0	1	80.0	2	51.6
Cancer of Pancreas (157)	3	40.3	1	28.4	4	36.5*
Cancer of Respiratory System (160-163)	42	95.4	12	58.5	54	83.7
Cancer of Larynx (161)	3	149.7	1	106.7	4	136.0
Cancer of Lung (162-163)	39	93.8	11	56.8	50	82.0
Cancer of Skin (172-173)	1	40.8	1	94.6	2	57.1
Cancer of Breast (174)	0	-	0	-	0	-
Cancer of Prostate (185)	5	52.2	2	39.8	7	48.0*
Cancer of Testis (186-187)	1	119.2	0	-	1	85.2
Cancer of Bladder (188)	4	94.1	2	93.3	6	93.9
Cancer of Kidney (189)	2	60.5	1	66.2	3	62.3
Cancer of Brain and CNS (191-192)	6	154.9	1	61.8	7	127.5
Lymphatic & Hematopoietic Cancer (200-209)	20	148.5	8	131.2	28	143.1
Lymphosarcoma and Reticulosarcoma (200)	5	169.5	2	153.2	7	164.5
Hodgkin's Disease (201)	3	178.8	0	-	3	127.4
Leukemia & Aleukemia (204-207)	5	90.7	5	196.6	10	124.2
Other Lymphatic Tissue Cancer (202,203,208)	6	190.8	1	67.7	7	151.5
Benign Neoplasms (210-239)	1	56.7	2	260.5	3	118.6
Diabetes Mellitus (250)	3	29.8*	1	21.2	4	27.1†
Diseases of Blood (280-289)	4	257.5	1	138.0	5	219.5
Diseases of Nervous System (320-389)	4	71.9	1	40.9	5	62.5
Diseases of Circulatory System (390-458)	284	77.0†	137	77.6†	421	77.2†
Chronic Rheumatic Heart Disease (393-398)	1	15.3*	1	36.3	2	21.5†
Arteriosclerotic Heart Disease (410-413)	224	86.5*	105	85.1	329	86.0†
Vascular lesions of CNS (430-438)	32	61.3†	14	54.2*	46	59.0†
Nonmalignant Respiratory Disease (460-519)	27	64.7*	12	58.2	39	62.5†
Pneumonia (480-486)	10	63.7	5	65.4	15	64.3
Emphysema (492)	7	64.9	2	36.6	9	55.4
Diseases of Digestive System (520-577)	29	86.8	9	61.6	38	79.1
Cirrhosis of Liver (551)	20	116.1	6	83.8	26	106.6
Diseases of Genito-Urinary System (580-629)	4	42.2	1	22.5	5	35.9*
Senility & Ill-Defined Conditions (780-799)	1	12.2†	1	27.2	2	16.9†
Accidents, Poisonings, & Violence (E800-E998)	67	96.7	29	103.6	96	98.7
Accidents (800-949)	44	96.4	15	81.8	59	92.3
Motor Vehicle Accidents (810-827)	25	117.4	6	72.1	31	104.6
Suicide (950-959)	20	128.8	13	203.3*	33	150.5*

*Significant at 0.05

†Significant at 0.01

TABLE 21

Observed Deaths by Cause and SMRs for the Total Cohort at Richmond
and El Segundo Refineries, by Latency

Cause of Death (8th ICDA)	Latency					
	<10 years		10-19 years		20+ years	
	Obs.	SMR	Obs.	SMR	Obs.	SMR
All Causes	169	65.4†	388	76.5†	1735	72.2†
Infective and Parasitic Diseases (000-139)	2	30.5	2	23.2*	10	45.5†
All Cancers (140-209)	21	58.7*	72	79.7	369	76.1†
Cancer of Buccal Cavity and Pharynx (140-149)	0	-	1	32.4	8	53.3
Cancer of Digestive System (150-159)	2	22.6*	14	55.2*	109	77.6†
Cancer of Esophagus (150)	0	-	1	48.6	11	94.3
Cancer of Stomach (151)	0	-	5	90.9	21	79.0
Cancer of Large Intestine (153)	2	77.1	2	27.5*	36	78.0
Cancer of Rectum (154)	0	-	4	131.8	14	87.0
Cancer of Liver (155-156)	0	-	0	-	6	63.4
Cancer of Pancreas (157)	0	-	2	41.6	18	65.5
Cancer of Respiratory System (160-163)	8	96.9	25	91.4	102	63.4†
Cancer of Larynx (161)	0	-	2	151.5	7	95.7
Cancer of Lung (162-163)	8	104.5	23	89.9	93	61.1†
Cancer of Skin (172-173)	1	79.3	2	83.4	7	97.9
Cancer of Breast (174)	0	-	1	117.1	2	135.6
Cancer of Prostate (185)	0	-	0	-	34	85.0
Cancer of Testis (186-187)	0	-	1	90.0	1	72.1
Cancer of Bladder (188)	0	-	0	-	12	71.8
Cancer of Kidney (189)	2	243.8	3	125.2	8	69.0
Cancer of Brain and CNS (191-192)	2	87.2	7	164.3	13	119.0
Lymphatic & Hematopoietic Cancer (200-209)	2	30.4	12	107.3	50	115.7
Lymphosarcoma and Reticulosarcoma (200)	0	-	5	180.7	12	128.7
Hodgkin's Disease (201)	0	-	1	46.1	3	82.4
Leukemia & Aleukemia (204-207)	1	38.3	1	23.2	20	111.1
Other Lymphatic Tissue Cancer (202,203,208)	1	135.2	5	263.3	14	121.9
Benign Neoplasms (210-239)	1	93.5	0	-	4	75.1
Diabetes Mellitus (250)	0	-	0	-	17	47.7†
Diseases of Blood (280-289)	0	-	1	88.5	5	96.2
Diseases of Nervous System (320-389)	1	27.5	1	19.5	10	60.8
Diseases of Circulatory System (390-458)	43	54.8†	186	80.0†	999	73.6†
Chronic Rheumatic Heart Disease (393-398)	2	42.1	5	62.3	12	65.5
Arteriosclerotic Heart Disease (410-413)	33	66.0*	152	92.6	739	77.6†
Vascular lesions of CNS (430-438)	5	51.0	12	45.2†	141	70.1†
Nonmalignant Respiratory Disease (460-519)	2	22.2*	12	54.4*	91	57.7†
Pneumonia (480-486)	1	23.3	2	21.8*	32	55.8†
Emphysema (492)	0	-	7	145.3	19	44.2†
Diseases of Digestive System (520-577)	8	57.6	20	63.1*	69	66.2†
Cirrhosis of Liver (551)	4	53.8	15	83.5	41	81.2
Diseases of Genito-Urinary System (580-629)	4	87.4	3	41.1	15	46.5†
Senility & Ill-Defined Conditions (780-799)	1	24.0	1	14.9*	8	30.9†
Accidents, Poisonings, & Violence (E800-E998)	79	86.3	71	83.7	93	71.3†
Accidents (800-949)	58	92.3	41	73.8	47	54.2†
Motor Vehicle Accidents (810-827)	32	90.0	19	71.2	23	68.0
Suicide (950-959)	18	115.9	30	148.7*	40	120.3

*Significant at 0.05

†Significant at 0.01

TABLE 22

Observed Deaths by Cause and SMRs for the Total Cohort at Richmond
and El Segundo Refineries, By Length of Employment

Cause of Death (8th ICDA)	Length of Employment					
	<5 years		5-14 years		15+ years	
	Obs.	SMR	Obs.	SMR	Obs.	SMR
All Causes	262	80.1†	525	78.9†	1505	69.2†
Infective and Parasitic Diseases (000-139)	2	45.7	1	55.8	6	27.2†
All Cancers (140-209)	47	84.5	89	72.9†	326	75.3†
Cancer of Buccal Cavity and Pharynx (140-149)	0	-	1	25.4	8	59.4
Cancer of Digestive System (150-159)	7	53.8	17	50.0†	101	79.1
Cancer of Esophagus (150)	0	-	3	108.1	9	86.1
Cancer of Stomach (151)	0	-	2	28.9	24	96.6
Cancer of Large Intestine (153)	4	93.6	5	47.5	31	75.3
Cancer of Rectum (154)	1	70.9	4	101.1	13	87.6
Cancer of Liver (155-156)	0	-	0	-	6	67.4
Cancer of Pancreas (157)	2	76.4	2	30.8	16	64.8
Cancer of Respiratory System (160-163)	21	121.5	34	89.9	80	56.6†
Cancer of Larynx (161)	0	-	1	57.3	8	121.4
Cancer of Lung (162-163)	21	128.4	33	92.8	70	52.4†
Cancer of Skin (172-173)	1	58.1	4	145.2	5	79.0
Cancer of Breast (174)	0	-	1	93.2	2	209.8
Cancer of Prostate (185)	0	-	4	65.1	30	83.8
Cancer of Testis (186-187)	1	88.0	0	-	1	74.4
Cancer of Bladder (188)	0	-	0	-	12	79.3
Cancer of Kidney (189)	4	284.1	3	97.2	6	58.1
Cancer of Brain and CNS (191-192)	3	105.2	8	168.2	11	111.5
Lymphatic & Hematopoietic Cancer (200-209)	3	38.0	11	78.3	50	128.1
Lymphosarcoma and Reticulosarcoma (200)	0	-	3	94.5	14	162.7
Hodgkin's Disease (201)	0	-	1	41.7	3	85.0
Leukemia & Aleukemia (204-207)	0	-	2	36.2	20	122.4
Other Lymphatic Tissue Cancer (202,203,208)	3	219.9	5	178.0	12	120.6
Benign Neoplasms (210-239)	1	89.1	1	47.4	3	61.2
Diabetes Mellitus (250)	0	-	3	32.2*	14	43.5†
Diseases of Blood (280-289)	0	-	2	134.6	4	84.1
Diseases of Nervous System (320-389)	1	24.9	2	31.8	9	60.4
Diseases of Circulatory System (390-458)	84	71.1†	256	80.1†	888	72.2†
Chronic Rheumatic Heart Disease (393-398)	2	48.1	4	44.2	13	72.6
Arteriosclerotic Heart Disease (410-413)	64	76.2*	202	90.6	658	76.6†
Vascular lesions of CNS (430-438)	13	96.2	23	54.9†	122	67.0†
Nonmalignant Respiratory Disease (460-519)	6	44.7*	25	74.3	74	52.3†
Pneumonia (480-486)	1	17.7*	8	59.3	26	50.4†
Emphysema (492)	2	80.1	6	79.7	18	46.6†
Diseases of Digestive System (520-577)	17	88.4	27	74.1	53	56.2†
Cirrhosis of Liver (551)	14	118.0	19	95.9	27	61.0†
Diseases of Genito-Urinary System (580-629)	3	72.2	4	40.8	15	49.7†
Senility & Ill-Defined Conditions (780-799)	1	18.5	5	58.9	4	17.4†
Accidents, Poisonings, & Violence (E800-E998)	79	88.2	83	87.0	81	66.5†
Accidents (800-949)	56	94.7	52	81.3	38	46.3†
Motor Vehicle Accidents (810-827)	30	92.3	24	77.5	20	61.4*
Suicide (950-959)	20	119.9	27	126.6	41	132.6

*Significant at 0.05

†Significant at 0.01

TABLE 23

Observed Deaths by Cause and SMRs for all Cohort Members by Hire Date

Cause of Death (8th ICDA)	Hire Date			
	1948 or Before		After 1948	
	Obs.	SMR	Obs.	SMR
All Causes	1932	73.5†	360	66.6†
Infective and Parasitic Diseases (000-139)	13	41.2†	1	17.8*
All Cancers (140-209)	393	6.5†	69	1.2†
Cancer of Buccal Cavity and Pharynx (140-149)	9	5.0	0	-
Cancer of Digestive System (150-159)	111	72.9†	14	62.4
Cancer of Esophagus (150)	9	73.2	3	143.9
Cancer of Stomach (151)	24	79.3	2	52.2
Cancer of Large Intestine (153)	34	70.0*	6	80.8
Cancer of Rectum (154)	17	95.3	1	42.3
Cancer of Liver (155-156)	6	55.2	0	-
Cancer of Pancreas (157)	18	61.8*	2	42.9
Cancer of Respiratory System (160-163)	111	67.5†	24	75.0
Cancer of Larynx (161)	8	02.9	1	79.7
Cancer of Lung (162-163)	101	65.1†	23	75.7
Cancer of Skin (172-173)	6	77.0	4	132.8
Cancer of Breast (174)	2	24.5	1	74.7
Cancer of Prostate (185)	33	60.5	1	42.3
Cancer of Testis (186-187)	1	48.0	1	59.1
Cancer of Bladder (188)	12	68.2	0	-
Cancer of Kidney (189)	9	73.3	4	157.5
Cancer of Brain and CNS (191-192)	17	134.6	5	103.2
Lymphatic & Hematopoietic Cancer (200-209)	58	120.9	6	46.2
Lymphosarcoma and Reticulosarcoma (200)	16	149.6	1	36.6
Hodgkin's Disease (201)	2	39.9	2	74.7
Leukemia & Aleukemia (204-207)	22	110.2	0	-
Other Lymphatic Tissue Cancer (202, 203, 208)	17	146.0	3	121.0
Benign Neoplasms (210-239)	4	62.8	1	56.7
Diabetes Mellitus (250)	17	44.1†	0	-
Diseases of Blood (280-289)	6	103.6	0	-
Diseases of Nervous System (320-389)	10	53.1*	2	31.4
Diseases of Circulatory System (390-458)	1106	75.5†	122	60.1†
Chronic Rheumatic Heart Disease (393-398)	18	72.1	1	16.3*
Arteriosclerotic Heart Disease (410-413)	825	81.1†	99	66.8†
Vascular lesions of CNS (430-438)	149	69.2†	9	40.8†
Nonmalignant Respiratory Disease (460-519)	93	56.0†	12	53.0*
Pneumonia (480-486)	32	52.0†	3	32.4*
Emphysema (492)	22	49.8†	4	89.0
Diseases of Digestive System (520-577)	78	67.1†	19	56.4†
Cirrhosis of Liver (551)	46	84.8	14	64.6
Diseases of Genito-Urinary System (580-629)	19	49.9†	3	49.4
Senility & Ill-Defined Conditions (780-799)	9	32.5†	1	11.0†
Accidents, Poisonings, & Violence (E800-E998)	133	77.5†	110	81.4*
Accidents (800-949)	74	62.6†	72	82.9
Motor Vehicle Accidents (810-827)	34	68.3*	40	86.4
Suicide (950-959)	54	128.8	34	125.9

*Significant at 0.05

†Significant at 0.01

TABLE 24

Observed Deaths by Cause and SMRs for all Cohort Members
by Hire Date at the El Segundo Refinery

Cause of Death (8th ICDA)	Hire Date			
	1948 or Before		After 1948	
	Obs.	SMR	Obs.	SMR
All Causes	644	70.2†	141	65.0†
Infective and Parasitic Diseases (000-139)	9	83.3	0	-
All Cancers (140-209)	130	72.0†	30	73.8
Cancer of Buccal Cavity and Pharynx (140-149)	2	35.5	0	-
Cancer of Digestive System (150-159)	33	62.0†	7	73.4
Cancer of Esophagus (150)	3	70.5	1	116.1
Cancer of Stomach (151)	5	47.8	0	-
Cancer of Large Intestine (153)	9	52.6*	4	125.1
Cancer of Rectum (154)	4	63.9	1	98.6
Cancer of Liver (155-156)	4	106.0	0	-
Cancer of Pancreas (157)	6	58.6	1	50.7
Cancer of Respiratory System (160-163)	41	70.4*	12	90.2
Cancer of Larynx (161)	2	73.0	1	190.0
Cancer of Lung (162-163)	39	71.0*	11	87.1
Cancer of Skin (172-173)	2	73.9	1	84.4
Cancer of Breast (174)	0	-	1	113.3
Cancer of Prostate (185)	10	69.5	1	87.9
Cancer of Testis (186-187)	0	-	0	-
Cancer of Bladder (188)	2	32.0	0	-
Cancer of Kidney (189)	3	69.4	1	95.4
Cancer of Brain and CNS (191-192)	6	136.1	1	52.3
Lymphatic & Hematopoietic Cancer (200-209)	15	89.1	3	58.3
Lymphosarcoma and Reticulosarcoma (200)	3	80.3	1	91.4
Hodgkin's Disease (201)	1	58.1	0	-
Leukemia & Aleukemia (204-207)	8	114.1	0	-
Other Lymphatic Tissue Cancer (202, 203, 208)	3	73.0	2	194.3
Benign Neoplasms (210-239)	3	135.2	0	-
Diabetes Mellitus (250)	5	37.4*	0	-
Diseases of Blood (280-289)	2	99.2	0	-
Diseases of Nervous System (320-389)	1	15.2*	1	40.5
Diseases of Circulatory System (390-458)	374	73.1†	53	61.7†
Chronic Rheumatic Heart Disease (393-398)	10	114.8	1	40.5
Arteriosclerotic Heart Disease (410-413)	275	76.9†	44	70.3*
Vascular lesions of CNS (430-438)	50	67.1†	3	31.1*
Nonmalignant Respiratory Disease (460-519)	30	51.1†	4	41.8
Pneumonia (480-486)	12	56.0*	2	52.4
Emphysema (492)	7	44.2*	2	99.7
Diseases of Digestive System (520-577)	21	52.0†	8	59.8
Cirrhosis of Liver (551)	13	69.2	6	70.3
Diseases of Genito-Urinary System (580-629)	6	46.1	1	41.0
Senility & Ill-Defined Conditions (780-799)	3	31.9*	0	-
Accidents, Poisonings, & Violence (E800-E998)	44	75.5	37	76.7
Accidents (800-949)	24	59.9†	23	74.3
Motor Vehicle Accidents (810-827)	11	65.6	12	74.1
Suicide (950-959)	19	131.5	13	128.6

*Significant at 0.05

†Significant at 0.01

TABLE 25

Observed Deaths by Cause and SMRs for all Cohort Members
by Hire Date at the Richmond Refinery

Cause of Death (8th ICDA)	Hire Date			
	1948 or Before		After 1948	
	Obs.	SMR	Obs.	SMR
All Causes	1288	75.3†	219	67.7†
Infective and Parasitic Diseases (000-139)	4	19.3†	1	29.1
All Cancers (140-209)	263	78.9†	39	69.4*
Cancer of Buccal Cavity and Pharynx (140-149)	7	67.1	0	-
Cancer of Digestive System (150-159)	78	78.8*	7	54.3
Cancer of Esophagus (150)	6	74.7	2	163.5
Cancer of Stomach (151)	19	95.9	2	90.4
Cancer of Large Intestine (153)	25	79.5	2	47.2
Cancer of Rectum (154)	13	112.2	0	-
Cancer of Liver (155-156)	2	28.2	0	-
Cancer of Pancreas (157)	12	63.5	1	37.2
Cancer of Respiratory System (160-163)	70	65.8†	12	64.2
Cancer of Larynx (161)	6	119.1	0	-
Cancer of Lung (162-163)	62	61.9†	12	67.7
Cancer of Skin (172-173)	4	78.6	3	164.1
Cancer of Breast (174)	2	179.2	0	-
Cancer of Prostate (185)	23	86.4	0	-
Cancer of Testis (186-187)	1	72.3	1	92.3
Cancer of Bladder (188)	10	88.1	0	-
Cancer of Kidney (189)	6	75.4	3	201.2
Cancer of Brain and CNS (191-192)	11	133.8	4	136.3
Lymphatic & Hematopoietic Cancer (200-209)	43	138.0	3	38.3
Lymphosarcoma and Reticulosarcoma (200)	13	186.9	0	-
Hodgkin's Disease (201)	1	30.4	2	119.1
Leukemia & Aleukemia (204-207)	14	108.1	0	-
Other Lymphatic Tissue Cancer (202,203,208)	14	185.8*	1	69.0
Benign Neoplasms (210-239)	1	24.1	1	94.7
Diabetes Mellitus (250)	12	47.7†	0	-
Diseases of Blood (280-289)	4	106.0	0	-
Diseases of Nervous System (320-389)	9	73.3	1	25.6
Diseases of Circulatory System (390-458)	732	76.8†	69	58.9†
Chronic Rheumatic Heart Disease (393-398)	8	49.2*	0	-
Arteriosclerotic Heart Disease (410-413)	550	83.3†	55	64.3†
Vascular lesions of CNS (430-438)	99	70.3†	6	48.3
Nonmalignant Respiratory Disease (460-519)	63	58.7†	8	61.2
Pneumonia (480-486)	20	49.9†	1	18.3
Emphysema (492)	15	52.9†	2	80.3
Diseases of Digestive System (520-577)	57	75.1*	11	54.2*
Cirrhosis of Liver (551)	33	93.1	8	60.9
Diseases of Genito-Urinary System (580-629)	13	51.9*	2	55.1
Senility & Ill-Defined Conditions (780-799)	6	32.8†	1	17.9*
Accidents, Poisonings, & Violence (E800-E998)	89	76.5*	73	84.0
Accidents (800-949)	50	64.0†	49	87.7
Motor Vehicle Accidents (810-827)	23	69.7	28	93.0
Suicide (950-959)	35	127.3	21	124.3

*Significant at 0.05

†Significant at 0.01

TABLE 26

Observed Deaths and SMRs, by Latency and Duration of Employment
 from Lymphatic and Hematopoietic Cancer
 among Richmond and El Segundo Refinery Workers

Length of Employment (years)								
Latency	<5		5-14		15+		TOTAL	
	Obs.	SMR	Obs.	SMR	Obs.	SMR	Obs.	SMR
<10	0	-	2	65.3	0	-	2	30.4
10-19	2	94.7	5	89.4	5	143.8	12	107.3
20+	1	44.2	4	74.2	45	126.6	50	115.7
TOTAL	3	38.0	11	78.3	50	128.1	64	105.0

Mean exposure = 25.9 years

Mean latency = 32.9 years

TABLE 27

Observed Deaths and SMRs, by Latency and Duration of Employment
from Leukemia and Aleukemia
among Richmond and El Segundo Refinery Workers

Length of Employment (years)

Latency	<u><5</u>		<u>5-14</u>		<u>15+</u>		<u>TOTAL</u>	
	Obs.	SMR	Obs.	SMR	Obs.	SMR	Obs.	SMR
<10	0	-	1	83.3	0	-	1	38.3
10-19	0	-	0	-	1	75.1	1	23.2
20+	0	-	1	46.2	19	126.7	20	111.1
TOTAL	0	-	2	36.2	20	122.4	22	88.3

Mean exposure = 31.3 years

Mean latency = 39.6 years

TABLE 28

Observed Deaths, Expected Deaths and SMRs
for Malignant Cancer of the Brain and CNS (191-192),
Benign Brain Tumors (225.0) and Brain Tumors, Nature Unspecified (238)
for Total Cohort at the Richmond and El Segundo Refineries

Cause of Death (8th ICD)	Observed Deaths	Expected Deaths	SMR	95% C.I.
Malignant Cancer of Brain and CNS (191-192)	22	17.48	125.9	78.7 - 190.7
Benign Brain Tumors (225.0)	0	1.16	0	-
Brain Tumors, Nature Unspecified (238)	1	4.36	22.9	0.6 - 127.2
Malignant, Benign and Unspecified Brain Tumors (191-192, 225.0, 238)	23	23.00	100.0	65.4 - 150.2

NOTE: Expected deaths from benign brain tumors (225.0) and brain tumors, nature unspecified (238), were based on 1968 U.S. death rates obtained from the National Center for Health Statistics.

TABLE 29

Average annual age-adjusted mortality rates (per 100,000) for all cancers,
digestive cancer and lung cancer in white males
in Contra Costa County, Los Angeles County, and U.S., 1950-1969

Location	All Cancers	Digestive Cancer*	Lung Cancer	Leukemia, Aleukemia	Non-Hodgkin's Lymphoma
Contra Costa County (Richmond)	174.4	55.4	42.8	8.7	5.3
Los Angeles County (El Segundo)	174.8	55.9	41.0	8.7	5.6
United States	174.0	58.3	38.0	8.8	4.9

*Data available for esophagus, stomach, large intestine, rectum, biliary passages
and liver, and pancreas only.

TABLE 30

Comparison of Previous Study Results with Chevron Refineries Results, by Cancer Site

Cancer Site	<u>Previous Studies</u>		<u>Chevron Refineries</u>	
	Study Author	SMR or Risk Ratio	Total Cohort SMR	Minimum Detectable Mortality Ratio
Brain	Theriault	SMR=652	125.9	2.03
	Thomas	PMR=221		
	Hanis [1982]	SMR=102		
	Schottenfeld	SMR=124		
	Devine	SMR=108		
Respiratory	Hanis [1979]	RR=1.89	68.7	1.47
Esophagus	Hanis [1979]	RR=3.25	83.5	2.16
	(+ stomach)			
	Rushton	SMR=114		
Stomach	Hanis [1979]	RR=3.25	76.2	1.70
	(+ esophagus)			
	Thomas	PMR=152		
Large Intestine	Rushton	SMR=107	71.4	1.53
Rectum	Rushton	SMR=103	89.1	1.95
	Schottenfeld	SMR=129		
Leukemia	Decoufle	SMR=682	88.3	1.84
	Thomas	PMR=183		
	Wen	SMR=114		
	Devine	SMR=113		
Non-Hodgkins Lymphoma	Thomas	PMR=132	134.3	1.79
	Devine	SMR=111		
Kidney	Hanis [1982]	SMR=155	87.7	2.14
	Wen	SMR=112		