Torrance III

An Updated Mortality Study of Workers at a Petroleum Refinery in Torrance, California, 1959-97

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Summary

The present investigation represents an update of a previous cohort mortality study of employees at the Mobil (now ExxonMobil) Torrance, California refinery. The updated cohort consisted of 3,328 workers who were employed at the refinery for at least one year between 1959 and 1997. There were 2,965 (89.1%) male and 363 (10.9%) female employees. The vital status of the cohort was determined through a variety of sources, including company employment or retirement records, the Social Security Administration's Death Master File, and the National Center for Health Statistics' National Death Index. The updated study covered an observation period of 38 years from 1960 to 1997, with a total of 60,612 person-years of observation. A total of 705 (21.2%) cohort members were identified to have died. Mortality data were analyzed in terms of cause-specific standardized mortality ratios (SMRs) and 95% confidence intervals (95% CIs), with expected deaths based on US national cause-gender-race-year-age-specific mortality rates.

The overall mortality of the cohort was significantly lower than expected when compared with the US general population (SMR=81.9, 95% CI: 76.0-88.2). Overall cancer mortality was also lower than expected (SMR=79.8, 95% CI: 67.9-93.1). For specific cancer sites, significant mortality deficits were observed for cancer of the digestive system (SMR=70.9, 95% CI: 49.4-98.6) and lung cancer (SMR=76.2, 95% CI: 56.9-100.0). No significant increase was reported for any site-specific cancer. For nonmalignant diseases, no significant increase was observed for any cause. In particular, significant mortality deficits were reported for ischemic heart disease (SMR=87.7, 95% CI: 77.2-99.3), chronic endocardial disease and other myocardial insufficiencies (SMR=8.3, 95% CI: 0.2-46.0), all other heart disease (SMR=64.2, 95% CI: 43.0-92.2), and influenza and pneumonia (SMR=59.2, 95% CI: 33.1-97.6). Detailed analysis by length of employment did not reveal any significant mortality excess or upward trend.

Analyses of male workers by job classification (process and maintenance) were conducted. Among maintenance workers, mortality from cirrhosis of the liver (SMR=190.1, 95% CI: 101.2-325.1) and suicide (SMR=208.6, 95% CI: 111.1-356.7) was significantly elevated. However, these mortality excesses did not appear to be related to employment at the refinery. No other

causes of death showed significant increase among maintenance workers. A similar separate analysis was conducted for process workers, and no significant excess was detected for any cause.

The findings from the present study were discussed in conjunction with results from previous investigations of employees at the Torrance refinery as well as with results from other refinery studies. Potential limitations of the study were also discussed.

INTRODUCTION

Refinery workers are potentially exposed to a wide range of petroleum-derived hydrocarbons and chemical substances used in the manufacturing of petroleum fuels and lubricants. Specific substances in the working environment of petroleum refineries have previously been identified by the International Agency for Research on Cancer (IARC), which include: aromatic amines (e.g., anisidines), arsenic compounds, asbestos, benzene, bitumens, butadiene, carbazole, chlorinated hydrocarbons, chromium and chromium compounds, ethylene dibromide, ethylene dichloride, hydrazine, lead and lead compounds, mineral oils, nickel and nickel compounds, phenylenediamine, polycyclic aromatic compounds, and silica [IARC, 1989].

The Mobil (now ExxonMobil) Torrance, California refinery first started operations under General Petroleum Corporation of California in 1929. In 1959 the Torrance refinery became part of Mobil Oil Co. The refinery processes approximately 160,000 barrels of oil a day and produces a variety of petroleum products including gasoline, diesel fuels, jet fuel, liquefied petroleum gases, petroleum coke and sulfur.

In 1985, Enterline and Henderson completed a retrospective cohort mortality study of white male workers at the Torrance refinery who worked for at least one year between January 1, 1959 and December 31, 1978 [Enterline and Henderson, 1985]. The vital status of these workers was ascertained through December 31, 1978. The cohort study was subsequently updated and expanded to include all employees at the refinery who worked for at least a year between January 1, 1959 and December 31, 1987, with vital status follow-up extended to December 31, 1987 [Milcarek, et al., 1994]. However, only analyses for white males were presented.

The objective of the present investigation was to update and expand the previous cohort study and to continue monitoring the mortality patterns of the Torrance refinery workers. In the present update, enrollment in the study was extended to cover an additional ten years of employment eligibility (1988-1997). Vital status follow-up was extended from December 31, 1987 to December 31, 1997.

MATERIALS AND METHODS

The expanded cohort consisted of all Mobil employees who had worked for at least a year at the Torrance refinery between January 1, 1959 and December 31, 1997. The cohort members were identified through a combination of personnel records located on-site and computerized payroll files. Information abstracted from these records included social security number, name, gender, race, date of birth, date of employment, employment status on the closing date of the study, vital status on the closing date of the study, and date of retirement, separation, or death when applicable. Employment histories of individuals in the previous cohort were updated from 1987 to 1997. For each employee, the employment history data consisted of the beginning and ending dates for each job, job titles and departments.

The vital status of cohort members as of December 31, 1997 was ascertained through several sources, including company employment or retirement records, records at Pension Benefits Information, Inc., the Social Security Administration's Death Master File, and the National Center for Health Statistics' National Death Index. The Death Master File is a national database of all deaths reported to the Social Security Administration since 1939. Vital status of an individual is ascertained by matching the last name and social security number. The National Death Index (NDI), established in 1979, is a national death registry designed to facilitate health investigations. Matching is based on the full name, social security number, birth date, gender, race and, in some cases, father's surname. Vital status information as well as causes of death of study subjects are provided by NDI through a service known as "NDI Plus." In the present update, causes of death for known decedents were obtained from either NDI Plus or death certificates. The underlying and contributory causes of death were coded or converted to the 8th Revision of the International Classification of Diseases (ICD8).

Statistical analyses were based on cause-specific standardized mortality ratios (SMRs). Person-years of observation were classified by age (5-year groups), gender, race and calendar year (5-year groups). The race of approximately 5% cohort members was unknown, and these workers were assumed to be white in the analyses. Expected deaths were calculated by applying the US

national age-cause-gender-race-year-specific death rates to the corresponding person-years in the cohort. Cause-specific standardized mortality ratios (SMRs) were computed by expressing the observed deaths as percentages of the expected. The actual calculation was performed through the University of Pittsburgh's OCMAP program, with standard mortality rates derived from the Mortality and Population Data System (MPDS) [Marsh et al., 1998]. Analyses were performed for the entire cohort and for subcohorts stratified by gender, length of employment and time since first employment at the refinery. Trend analyses by length of employment were based on the method described by Breslow and Day [1987]. To investigate mortality by job category, male hourly employees at the Torrance refinery were classified into two major job categories: (i) process workers, and (ii) maintenance craft workers. This latter subcohort of maintenance craft workers consisted of individuals involved in a broad range of labor and maintenance activities in the mechanical and service divisions of the refinery. Examples of maintenance jobs included pipefitter, auto mechanic, welder, insulator, and painter.

In addition to analyses conducted using the routine OCMAP program, a special analysis for lymphohematopoietic malignancies was also performed. In the US, because of the way in which mortality rates by ICD8 categories are tabulated by the National Center for Health Statistics (NCHS), analyses of non-Hodgkin's lymphoma (NHL) and multiple myeloma (MM) in most occupational cohort studies are generally not reported as such. In the OCMAP program, NHL (ICD8 200 and 202) appears in two categories: "lymphosarcoma and reticulosarcoma" (ICD8 200) and "cancer of all other lymphatic and hematopoietic tissue" (ICD8 202, 203, 208, 209). Thus, part of NHL (ICD8 202, "other lymphomas") is reported together with MM (ICD8 203), polycythemia vera (ICD8 208) and myelofibrosis (ICD8 209). In the special analysis, NHL and MM were analyzed separately. In the OCMAP program, different types of leukemia were analyzed as one single group. Therefore, the following major types of leukemia were also analyzed separately: acute lymphatic (ICD8 204.0), chronic lymphatic (ICD8 204.1), acute myeloid (ICD8 205.0), and chronic myeloid leukemia (ICD8 205.1). US mortality rates for cell-type specific leukemias, NHL and MM compiled by the National Cancer Institute (NCI) based on data derived from the "Surveillance, Epidemiology, and End Results" (SEER) program were used in computing the expected deaths from these causes [Young et al., 1981; Reis et al., 1994].

In addition, because of the use of asbestos at the refinery in the past, separate analyses for asbestos-related diseases were also performed. The OCMAP program did not provide a separate analysis for asbestosis. The term asbestosis refers to pulmonary fibrosis caused by exposure to asbestos, or pulmonary fibrosis in persons with a documented asbestos exposure history. Since certifying physicians might not be aware of the decedents' asbestos exposure (if any), such deaths could have been coded simply as pulmonary fibrosis or pneumoconiosis. Therefore, mortality from "pulmonary fibrosis" or "pneumoconiosis" (ICD8 515-517) was analyzed. Expected deaths were based on US rates for pulmonary fibrosis obtained from the National Center for Health Statistics, NCHS (unpublished data by special request). For malignant peritoneal or pleural mesothelioma, mortality rates compiled by NCI were used [Connelly et al., 1987; Spirtas et al., 1986].

RESULTS

A total of 3,328 workers were eligible for inclusion in the updated study (Table 1). Eighty-five percent (85.9%) of the cohort members were white (including Hispanics), and 89.1% were male. Selected employment and demographic characteristics of the cohort are provided in Table 1. Approximately 80% were first employed in their twenties or thirties, and only 10.3% were hired at age 40 or older. A great majority (81.3%) of the cohort members were hired in or after 1950. Most cohort members (57.8%) were employed for at least 10 years at the refinery.

The maximum length of vital status follow-up was 38 years (January 1, 1960 to December 31, 1997). The average duration of follow-up was 18 years. A total of 1,356 (40.7%) cohort members had a follow-up of 20 years or more. The increase in person-years from the previous study (white males only) was 27,281 or 81.8% to a total of 60,612 (all cohort members). By the end of the follow-up period (December 31, 1997), 1,062 (31.9)% cohort members were still employed at the refinery, 1,561 (46.9%) had separated or retired, and 705 (21.2%) were known to have died. Information on vital status was 98.9% complete, with 38 (1.1%) separated employees lost to follow-up. Of the 705 cohort members identified to have died between 1959 and 1997, death certificate information (derived from death certificates themselves or from NDI Plus listings) was available for 695 deaths (98.6%). The causes of death of the remaining 10 deaths (1.3%) were unknown, and they were included in the overall SMR (all causes) calculations but not in cause-specific SMR calculations.

The number of observed deaths, SMRs and 95% confidence limits (95% CI) for selected causes for all workers are presented in Table 2. The total number of observed deaths was 705, compared with 860.43 expected (SMR=81.9, 95% CI: 76.0-88.2), indicating a statistically significant deficit in overall mortality. Mortality from all cancers was also significantly lower than expected. The number of observed cancer deaths was 161, versus 201.79 expected (SMR=79.8, 95% CI: 67.9-93.1).

For specific cancer sites, significant mortality deficits were observed for both cancer of the digestive system (35 observed vs. 49.38 expected deaths, SMR=70.9, 95% CI: 49.4-98.6) and cancer

of the respiratory system (53 observed vs. 71.50 expected deaths, SMR=74.1, 95% CI: 55.5-97.0). No significant increase was reported for any site-specific cancer.

For non-malignant diseases, the majority of SMRs were below 100, and no significant increase was observed for any cause. In particular, significant mortality deficits were reported for ischemic heart disease (SMR=87.7, 95% CI: 77.2-99.3), all other heart disease (SMR=64.2, 95% CI: 43.0-92.2), and influenza and pneumonia (SMR=59.2, 95% CI: 33.1-97.6).

A separate analysis for male employees is presented in Table 3. Because male employees represented approximately 90% of the entire cohort, their mortality experience was quite similar to that of the entire cohort. In particular, no significant increase in mortality from any cause of death was detected in male employees (Table 3). Similar to the total cohort, significant mortality deficits were observed for the following causes: all causes, all cancers, cancer of the digestive system, cancer of the respiratory system, ischemic heart disease, all other heart disease, and influenza and pneumonia.

Among the 363 female employees, only 11 deaths were reported. There were two deaths from breast cancer, one from lung cancer and one from cancer of the large intestine. For non-malignant diseases, there were two deaths from cerebrovascular disease, two from ischemic heart disease, one from generalized arteriosclerosis, and one from suicide. The cause of death of the remaining death was unknown. Given the small numbers of death, we will not present cause-specific SMRs among female employees.

Table 4 shows cause-specific mortality of male employees by length of employment at the refinery. None of the causes of death showed a statistically significant upward trend. Several causes appeared to show an upward trend, but none was statistically significant: all causes (χ^2_{trend}=1.86, p>0.05), bronchitis, emphysema and asthma (χ^2_{trend}=2.74, p>0.05), motor vehicle accidents (χ^2_{trend}=0.77, p>0.05), and suicides (χ^2_{trend}=2.25, p>0.05). None of the SMRs presented in Table 4 was significantly elevated, regardless of length of employment.

Long latent periods (decades) are usually required for chronic diseases to develop. In many instances, it would be more appropriate to examine mortality experience only after a certain lag period has elapsed. Table 5 shows mortality analysis by interval since hire (latency) for male employees. The category "cancer of other lymphopoietic tissue" showed a significantly elevated SMR in the shortest latency group (SMR=458.6, 95% CI: 148.9-1070.1, 5 observed deaths). This residual category includes non-Hodgkin's lymphoma, multiple myeloma, polycythemia vera and myelofibrosis. As stated in the previous section, a separate analysis of lymphatic and hematopoietic cancers based on a biologically meaningful classification has been conducted and the results will be presented below. Table 5 also shows that male employees with 20-39 years of latency experienced a significantly elevated SMR of 195.5 (95% CI: 115.9-309.0) for cirrhosis of the liver. On the other hand, several causes of death showed statistically significant mortality deficits by time since first employment, including all causes (<20, 20-39 years), all cancers (20-39 years), ischemic heart disease (<20 years), and cirrhosis of the liver (<20 years).

Workers were classified into broad categories of jobs (at least 6 months in the category). Separate mortality analyses were conducted for maintenance and process workers. Some workers were in both categories. Table 6 shows cause-specific mortality of male maintenance employees. Two causes of death showed significant increases: cirrhosis of the liver (SMR=190.1, 95% CI: 101.2-325.1) and suicide (SMR=208.6, 95% CI: 111.1-356.7). For cirrhosis of the liver the increase appeared to concentrate in workers with 10-29 years of employment in maintenance jobs (SMR=249.5, 95% CI: 107.7-491.6, 8 deaths); and for suicide, among those with 30 years or longer in maintenance jobs (SMR=1130.5, 95% CI: 136.8-4084.1, 2 deaths) (not shown in Table 6). No other SMRs were significantly elevated, and no upward trend was reported for any cause of death among male maintenance workers.

A similar analysis was carried out for male process employees (Table 7). The overall mortality was significantly less than expected (SMR=81.3, 95% CI: 70.9-92.8). Lung cancer also showed a significant deficit (SMR=46.7, 95% CI: 22.4-85.8). Similar to maintenance workers, process workers also showed an elevated mortality from cirrhosis of the liver, but the excess was not statistically significant (SMR=140.1, 95% CI: 60.5-276.1).

The specific categories of lymphatic and hematopoietic cancers used in the OCMAP program are based on the statistical classifications compiled by National Center for Health Statistics (NCHS) and do not permit a specific analysis for major cell-type specific leukemias, NHL or MM, which are more appropriate classifications from the biological point of view [Linet, 1985; Heath, 1982; Wintrobe et al., 1981; Wong and Raabe, 1995]. Therefore, analyses for these specific subcategories of lymphatic and hematopoietic cancers among male employees were carried out separately.

Table 8 shows that there was only one observed AML death among male employees, compared with 2.20 expected (SMR=45.4, 95% CI: 1.1-252.8). For CML, there were 2 observed deaths, approximately one more than the 1.02 expected (SMR=195.6, 95% CI: 23.7-706.6). No death from ALL was reported. For CLL, one death was observed, comparable to the 1.34 expected. There were 4 MM deaths, similar to the expected 3.28 (SMR=122.1, 95% CI: 33.3-312.5). Similarly, there were 9 NHL deaths, comparable to the 7.42 expected (SMR=121.4, 95% CI: 55.5-230.4). Table 8 also presents analysis by job category. No significant mortality increase in any disease subcategory was reported by job category.

Table 9 shows the mortality from lymphohematopoietic cancers of male employees by length of employment. There was no upward trend for any of the specific categories of lymphohematopoietic cancer. No significant increase was found for any length of employment. Analysis by time since first employment is also presented in Table 9. No significant increase was detected for any categories of lymphohematopoietic cancers for any latency group.

Because of the use of asbestos at the refinery in the past, mortality from asbestos-related diseases (asbestosis, lung cancer, and mesothelioma) among cohort members was examined. Although the OCMAP program provided an analysis for lung cancer, it did not provide any separate analysis for asbestosis or malignant mesothelioma of the peritoneum or pleura. Analyses for asbestosis (pulmonary fibrosis) and malignant mesothelioma of the peritoneum or pleura were performed separately. The term asbestosis refers to pulmonary fibrosis caused by exposure to asbestos, or pulmonary fibrosis in persons with a documented asbestos exposure history. The ICD code (8th revision) for asbestosis is

515.2, and is, therefore, part of the broad category "other non-malignant respiratory disease" (ICD8 460-519) in the OCMAP analysis. In the Torrance cohort, no death was attributed to asbestosis. However, since certifying physicians might not be aware of the decedents' asbestos exposure (if any), such deaths could have been coded simply as pulmonary fibrosis or pneumoconiosis. Therefore, the category "pulmonary fibrosis" was analyzed. For pulmonary fibrosis (ICD8 515-517), there were 3 observed deaths among all male cohort members, compared with 4.24 expected. The corresponding SMR for pulmonary fibrosis among male employees was 70.8 (95% CI: 14.6-207.0). One of the 3 male employees who died from pulmonary fibrosis had worked in both maintenance and process jobs, and the remaining two in administrative or technical jobs.

As stated above, lung cancer results were provided by the routine OCMAP program. The results for the overall cohort are presented in Table 2 (SMR=76.2, 95% CI: 56.9-100.0). The lung cancer SMR for all males was 76.0 (95% CI: 56.6-99.9). Exposure to asbestos has been linked to malignant peritoneal and pleural mesothelioma in epidemiologic studies. Malignant peritoneal mesothelioma is part of "malignant neoplasm of the peritoneum and retroperitoneal tissue" (ICD8 158), and malignant pleural mesothelioma is part of "malignant neoplasm of the pleura" (ICD8 163). The most comprehensive mortality rates for malignant peritoneal and pleural mesothelioma for the US are those compiled by the National Cancer Institute in the Surveillance, Epidemiology and End Results (SEER) program [Connelly et al., 1987; Spirtas et al., 1986]. In the SEER program, cases were selected having the International Classification of Diseases for Oncology (ICDO) morphology code 905 (mesothelial neoplasms) and topography codes 158 (peritoneum) or 163 (pleura). In addition, only malignant cases were included [Spirtas et al., 1986]. In the present study, diagnostic information was based entirely on death certificates, and no information on morphology was available. In the Torrance cohort, there was one death coded as ICD8 163 (malignant neoplasm of the pleura). Based on the SEER rates, approximately 1.08 deaths from malignant mesothelioma of the pleura were expected. The corresponding SMR was 92.6 (95% CI: 2.4-516.0).

DISCUSSION

In the discussion below, we will first compare some major results in the updated study to those previously reported for the Torrance cohort by Milcarek et al. [1994]. We will then discuss several specific findings in the updated study, which are of particular interest in epidemiologic studies of refinery workers.

Extended enrollment and follow-up in this update on Torrance refinery workers added 1,337 workers (+67.2%), 27,281 person-years (+81.8%) and 297 additional deaths (+72.8%). One of the reasons for the sizable increases was that only white males were included in the previous study, whereas no restriction on gender or race was imposed on cohort eligibility in the update. In the previous analysis 20.5% of cohort members were deceased, compared with 21.2% in this update. Updated results for the total cohort were consistent with earlier reports, which demonstrated a favorable overall mortality experience of the Torrance refinery workers. Based on national rates, the updated SMR of 81.9 for all causes showed a significant deficit of 18.1%, which was similar to the deficit previously observed (SMR=81). As in the previous study, the favorable overall mortality experience of these refinery workers might be attributed to the "healthy worker effect," whereby working populations exhibit decreased overall mortality due to initial selection into the workplace and maintenance of this healthier status through benefits derived from employment.

In terms of specific causes, for the cohort as a whole or the male subcohort, no significant mortality increase was observed for any cause of death. The earlier reports showed non-significant deficits for cancer of the digestive system and cancer of the respiratory system. In the updated study, similar deficits were observed, and, because of the larger numbers of deaths, the deficits for both cancer of the digestive system and cancer of the respiratory system were statistically significant. In the previous reports, a significant deficit of ischemic heart disease was reported. In the current update, a similar significant deficit was observed for ischemic heart disease. In addition, a significant deficit was also reported for the category "all other heart disease."

Analysis by length of employment also indicated that there was no work-related mortality pattern for male employees. No significant increase of mortality was found for any cause for any length of employment group, and no upward trend was detected for any cause of death. Analysis by latency (time since hire) showed that there was a significant mortality excess from the miscellaneous category "cancer of other lymphopoietic tissue" for the group with less than 20 years of latency (5 observed v. 1.09 expected, SMR=458.6). Of the 5 deaths in this category, one was a multiple myeloma (ICD8 203), and the other 4 were "other lymphomas" (ICD8 202). As discussed earlier, a proper analysis of NHL should include "lymphosarcoma and reticulosarcoma" (ICD8 200) and "other lymphomas" (ICD8 202). In the group with less than 20 years of latency, no death was observed for "lymphosarcoma and reticulosarcoma" (ICD8 200). Thus, according to the disease grouping provided in the OCMAP analysis, NHL was reported in two places: no death was attributed to "lymphosarcoma and reticulosarcoma" (ICD8 200) and 4 to "other lymphomas" (ICD8 202). When NHL (ICD8 200 and 202) was analyzed as a group (Table 9), the SMR was 298.3 (95% CI: 81.3-763.9) and not significant. The more important observation was that there was no upward trend by length of employment for NHL.

The finding of no association between NHL and employment at the Torrance refinery is consistent with the conclusion reached in a recent review of NHL in petroleum workers [Wong and Raabe, 2000a]. The review was based on more than 308,000 petroleum workers from the US, the UK, Canada, Australia, Italy and Finland. None of the individual studies showed a significant increase of NHL. For all studies combined, there were 408 observed NHL deaths, comparable to the 412.20 expected (SMR=99, 95% CI: 90-109). Specifically for US refinery studies, there were 317 observed deaths, slightly fewer than the 330.79 expected (SMR=96, 95% CI: 86-107). There is no evidence that employment at petroleum refineries is associated with an increased risk of NHL.

For male employees with 20-39 years of latency, mortality from cirrhosis of the liver was significantly elevated, but that for male employees with less than 20 years of latency was significantly low (Table 5). There was no upward trend of mortality from cirrhosis of the liver by length of employment (Table 4). Cirrhosis of the liver is associated with alcohol consumption. Unfortunately, no information on alcohol consumption was available in the study. Cirrhosis of the liver has not been

linked to any petrochemicals present at refineries. No other epidemiologic studies of petroleum refinery workers have reported an increased mortality from cirrhosis of the liver.

Because of potential differences in exposures and exposure patterns, separate analyses were performed for maintenance and process workers at the refinery. Among maintenance workers, mortality from cirrhosis of the liver was significantly elevated (13 observed v. 6.84 expected, SMR=190.1, 95% CI: 101.2-325.1). As discussed above, the excess of cirrhosis of the liver was not likely to be related to employment at the refinery. There was a significant increase of mortality from suicide among maintenance workers (13 observed v.6.23 expected, SMR=208.6, 95% CI: 111.1-356.7). However, there is no reason to believe that the increase was related to exposures at the refinery. Among process workers, no significant increase of mortality from any cause of death was detected.

As stated above, the OCMAP program does not provide analyses specific to subgroups of lymphohematopoietic cancers. When analyses were performed separately for ALL, CLL, AML, CML, MM and NHL, no significant increase was found for any category for the cohort as a whole or for the subcohorts of maintenance or process workers. However, it must be noted that the number of deaths for each category was small, with the possible exception of NHL (9 observed deaths v. 7.42 expected). Nevertheless, the data indicated that there was no increased mortality from any of the subcategories of lymphohematopoietic cancers.

Similar to other industrial facilities, asbestos was used at the Torrance refinery in the past, and detailed analyses of asbestos-related diseases were performed for male employees. Although specific exposure measurements were not available, data from the industry as a whole have indicated that asbestos concentrations at refineries were generally extremely low [IARC, 1989]. Among Torrance refinery employees, no death was attributed to "asbestosis" as the underlying cause of death. The term asbestosis refers to pulmonary fibrosis in persons with documented asbestos exposure history. Since certifying physicians might not be aware of the decedents' asbestos exposure, such deaths could have been coded simply as pulmonary fibrosis or pneumoconiosis. In terms of pulmonary fibrosis, 3 deaths were reported, compared with 4.24 expected (SMR=70.8, 95% CI: 14.6-207.0). One of the 3 fibrosis

deaths worked in both process and maintenance jobs, and the other two in administrative or technical jobs.

One death in the cohort was coded as ICD8 163 (malignant neoplasm of the pleura), whereas 1.08 deaths were expected. This individual worked for approximately 2 years in the late 1950s at the Torrance refinery, and died 4 years after termination. Epidemiologic studies have reported the average latency of malignant pleural mesothelioma to be around 30 to 40 years even among heavily exposed workers. The extremely short interval of 6 years between employment at the Torrance refinery in 1958 and death in 1960 does not support an association between the two. In addition to the malignant pleural cancer case, the words "malignant mesothelioma" were mentioned on another death certificate. The cause of death listed on the death certificate was "malignant mesothelioma, metastatic" (with no specific site), and coded as ICD8 199.1. According to the SEER criteria, the information provided on the death certificate was not sufficient to classify this death specifically as either malignant mesothelioma of the peritoneum or malignant mesothelioma of the pleura.

For lung cancer, an asbestos-related malignancy, no increase was found for the overall cohort or the subcohorts of maintenance or process workers. In fact, for all three groups, lung cancer mortality was slightly less than expected. Equally important is the observation that no upward trend by length of employment was detected. Thus, the data indicated that there was no relationship between lung cancer mortality and employment at the Torrance refinery. This finding is consistent with the conclusion reached in a recent review of petroleum workers [Wong and Raabe, 2000b]. The review was based on more than 350,000 petroleum workers from the US, the UK, Canada, Australia, Italy and Finland. Lung cancer SMRs from individual studies ranged from 44 to 107. For all studies combined, there were 5,695 observed lung cancer deaths, significantly fewer than the 7,056.25 expected (SMR=81, 95% CI: 79-90). For US refinery workers, there were 2,696 observed lung cancer deaths, significantly fewer than the 3,573.27 expected (SMR=75, 95% CI: 73-78). Thus, there was no indication that petroleum workers were at an increased risk of lung cancer.

It should be pointed out that there are some potential limitations in this study. Most limitations are typical of a historical mortality study of industrial populations. First, although both the percentage

of individuals with unknown vital status (1.1%) and the proportion of deaths with no death certificate information (1.3%) were low, it was possible, but unlikely, that some deaths from causes of interest might have been missed. We do not believe that such low percentages would have any significant impact on our results.

Second, the health endpoint in our study was mortality, which is a reasonable surrogate for incidence of many cancers. Analyses were based on the underlying cause of death listed on death certificates. As such, the investigation inherited the problems associated with death certificates (diagnostic accuracy, for example). No detailed clinical information was available on the deaths in our study. However, it must be pointed out that although detailed information derived from medical records or pathology reports may be more accurate than that based on death certificates, it would be inappropriate to use such information for comparisons with national mortality rates. In our study we compared diagnoses based on death certificates to national statistics which were derived from death certificates as well. Furthermore, our analysis was adjusted for calendar time, thus at least partially controlling for changes in survival and diagnostic practices.

As in most historical cohort mortality studies, little quantitative exposure data were available during the early part of the study, and analyses by quantitative exposure indices were not possible. In the present study, we relied on duration of employment and the broad classification of jobs (process and maintenance). Although such exposure surrogates could be informative, they might lack both sensitivity and specificity.

For some analyses in the overall cohort as well as in some subcohort analyses, particularly those stratified by job category or by length of employment, the numbers of deaths from some rare causes were small. As a result, the corresponding 95% CIs were wide and the findings must be interpreted with caution. However, for common disease categories such as all cancers, digestive cancer, lung cancer, prostate cancer, heart disease and non-malignant respiratory disease, the statistical power of the study was quite adequate.

Finally, information on lifestyle or exposures from employments elsewhere was not available, although such information would have been extremely helpful in interpreting some of the findings in the present study, such as alcohol consumption in relation to cirrhosis of the liver. From the methodological point of view, the most appropriate approach of incorporating lifestyle risk factors and exposures from employments elsewhere is the nested case-control study design.

CONCLUSION

This updated study has confirmed earlier findings of an overall favorable mortality experience of employees at the Torrance, California refinery, when compared with the US general population. In addition, significant mortality deficits were found for several causes of death. For the entire cohort, no significant increase was detected in any cause-specific mortality, which could be attributed to employment at the refinery. Furthermore, analyses by job category and length of employment also indicated that there was no mortality increase from any cause of death associated with employment at the refinery.

REFERENCES

Breslow NE and Day NE [1987]: *Statistical Methods in Cancer Research, Volume II – The Design and Analysis of Cohort Studies.* IARC Scientific Publications No. 82. International Agency for Research on Cancer, Lyon.

Connelly RR, Spirtas R, Myers MH, Percy CL, and Fraumeni JF [1987]: Demographic patterns for mesothelioma in the United States. J Natl Cancer Inst 78:10531060.

Enterline PE and Henderson V [1985]: *A report of the mortality experience of workers from a petroleum refinery at Torrance, California.* Technical report submitted to Mobil Oil Corporation.

Heath CW [1982]: The leukemias. In: *Cancer Epidemiology and Prevention* (Schottenfeld D, Fraumeni JF eds.). WB Saunders.

International Agency for Research on Cancer [1989]: *IARC monographs on the evaluation of carcinogenic risks to humans. Occupational exposures in petroleum refining; crude oil and major petroleum fuels, Volume 45.* World Health Organization.

Linet MS [1985]: *The Leukemias: Epidemiologic Aspects.* Oxford University Press.

Marsh GM, Youk AO, Stone RA, Sefcik S, and Alcon C [1998]: OCMAP-Plus: A program for the comprehensive analysis of occupational cohort data. *J Occup Environ Med* 40:351-362.

Milcarek BI, Collingwood KW, and Raabe GK [1994]: *An updated cohort mortality study of white male workers at the Torrance, California refinery, 1959-1987.* Technical report, Mobil Oil Corporation Medical Department.

Reis LAG, Miller BA, Hankey BF, Kosary CL, Harras A, and Edwards BK [1994]: *SEER Cancer Statistics Review, 1973-1991.* NIH Publication No. 94-2789, National Cancer Institute, Washington.

Spirtas R, Beebe GW, Connelly RR, Wright WE, Peters JM, Sherwin RP, Henderson BE, Stark A, Kovasznay BM, Davies JNP, Vianna NJ, Keehn RJ, Ortega LG, Hochholzer L, and Wagner JC [1986]: Recent trends in mesothelioma incidence in the United States. *Am J Ind Med* 9:397-407.

Wintrobe MM, Lee GR, Boggs DR, Bithell TC, Forester J, Athens JW, and Lukens JN [1981]: *Clinical Hematology* (8th ed.), Lea & Frbiger.

Wong O and Raabe GK [1995]: Cell-type specific leukemia analyses in a combined cohort of more than 208,000 petroleum workers in the United States and the United Kingdom, 1937-1989. *Regulatory Toxicology and Pharmacology* 21: 307-321.

Wong O and Raabe GK [2000a]: Non-Hodgkin's lymphoma and exposure to benzene in a multinational cohort of more than 308,000 petroleum workers, 1937 to 1996. *J Occup Environ Med* 42:554-568.

Wong O and Raabe GK [2000b]: A critical review of cancer epidemiology in the petroleum industry, with a meat-analysis of a combined database of more than 350,000 workers. *Regulatory Toxicology and Pharmacology* 32:78-98.

Young JL, Perry CL, and Asire AJ [1981]: *Surveillance, Epidemiology, and End Results: Incidence and Mortality Data.* NIH Publication No. 81-2300.

Table 1
Characteristics of the Torrance, California, cohort

	Number	%total
Total employees	3,328	100.0
Total person-years	60,612	100.0
Race		
White	2,859	85.9
Nonwhite	469	14.1
Gender		
Male	2,965	89.1
Female	363	10.9
Year of hire		
< 1950	623	18.7
≥ 1950	2,705	81.3
Duration of employment (yr)		
<10	1,403	42.2
10-29	1,472	44.2
30 +	453	13.6
Age at hire		
<20	317	9.5
20-39	2,669	80.2
40+	342	10.3
Age at death		
<50	64	9.1
50-59	91	12.9
60-69	186	26.4
70 +	364	51.6
Vital status (December 31, 1997)		
Alive	2,585	77.7
Dead	705	21.2
Unknown	38	1.1

Table 2
Cause-specific mortality of the entire cohort of employees at the Torrance refinery

Cause of death	OBS	EXP	SMR	95% Confidence limits Lower	Upper
All Causes of Death	705	860.43	81.9 **	76.0	88.2
All Malignant Neoplasms	161	201.79	79.8 **	67.9	93.1
Cancer of Buccal Cavity & Pharynx	3	4.97	60.4	12.5	176.4
Cancer of Digestive Organs & Peritoneum	35	49.38	70.9 *	49.4	98.6
Cancer of Esophagus	3	5.05	59.4	12.3	173.6
Cancer of Stomach	5	7.24	69.0	22.4	161.1
Cancer of Large Intestine	12	18.20	65.9	34.1	115.2
Cancer of Rectum	2	4.23	47.3	5.7	170.8
Cancer of Biliary Passages & Liver	1	4.28	23.4	0.6	130.3
Cancer of Pancreas	12	9.99	120.1	62.1	209.8
Cancer of All Other Digestive Organs	0	1.39	0.0	0.0	265.2
Cancer of Respiratory System	53	71.50	74.1 *	55.5	97.0
Cancer of Larynx	0	2.56	0.0	0.0	144.4
Cancer of Bronchus, Trachea, Lung	52	68.20	76.2 *	56.9	100.0
Cancer of All Other Respiratory	1	0.73	137.4	3.4	765.7
Cancer of Breast	3	1.56	192.4	39.7	562.1
All Uterine Cancers (Females only)	0	0.34	0.0	0.0	1073.6
Cancer of Cervix Uteri (Females only)	0	0.22	0.0	0.0	1693.6
Cancer of Other Female Genital Organs	0	0.35	0.0	0.0	1050.0
Cancer of Prostate (Males only)	18	18.98	94.8	56.2	149.9
Cancer of Testes and Other Male Genital Organs	0	0.54	0.0	0.0	678.7
Cancer of Kidney	3	4.79	62.7	12.9	183.2
Cancer of Bladder and Other Urinary Organs	2	5.73	34.9	4.2	126.0
Malignant Melanoma of Skin	4	2.73	146.3	39.9	374.7
Cancer of Eye	1	0.13	799.6	20.0	4455.3
Cancer of Central Nervous System	6	4.91	122.1	44.8	265.8
Cancer of Thyroid & Other Endocrine Glands	0	0.55	0.0	0.0	665.9
Cancer of Bone	0	0.54	0.0	0.0	689.2
Cancer of All Lymphatic, Haematopoietic Tissue	19	18.65	101.9	61.3	159.1
Lymphosarcoma & Reticulosarcoma	1	2.11	47.4	1.2	264.3
Hodgkins Disease	1	1.13	88.4	2.2	492.8
Leukemia & Aleukemia	5	7.37	67.8	22.0	158.3
Cancer of All Other Lymphopoietic Tissue	12	8.04	149.2	77.1	260.6
All Other Malignant Neoplasms	14	15.28	91.6	50.1	153.7
Benign Neoplasms	0	2.10	0.0	0.0	175.3
Diabetes Mellitus	10	14.30	69.9	33.5	128.6
Cerebrovascular Disease	40	50.78	78.8	56.3	107.3
All Heart Disease	289	326.64	88.5 *	78.6	99.3
Rheumatic Heart Disease	5	4.64	107.7	35.0	251.4
Ischemic Heart Disease	249	283.86	87.7 *	77.2	99.3
Chronic Endocard. Dis.; Other Myocard. Insuff.	1	12.12	8.3 **	0.2	46.0
Hypertension with Heart Disease	5	6.63	75.4	24.5	176.1
All Other Heart Disease	29	45.16	64.2 *	43.0	92.2
Hypertension w/o Heart Disease	3	2.30	130.4	26.9	381.0
Non-malignant Respiratory Disease	55	69.56	79.1	59.6	102.9
Influenza & Pneumonia	15	25.35	59.2 *	33.1	97.6
Bronchitis, Emphysema, Asthma	12	14.23	84.3	43.6	147.3
Bronchitis	3	2.28	131.5	27.1	384.3
Emphysema	9	10.95	82.2	37.6	156.0
Asthma	0	1.02	0.0	0.0	361.7
Other Non-malignant Respiratory Disease	28	31.37	89.3	59.3	129.0
Ulcer of Stomach & Duodenum	0	3.35	0.0	0.0	110.2
Cirrhosis of Liver	19	17.25	110.2	66.3	172.0
Nephritis & Nephrosis	5	4.33	115.5	37.5	269.5
All External Causes of Death	59	65.15	90.6	68.9	116.8
Accidents	37	38.97	94.9	66.8	130.9
Motor Vehicle Accidents	22	17.65	124.6	78.1	188.7
All Other Accidents	15	21.47	69.9	39.1	115.2
Suicides	17	15.73	108.1	63.0	173.1
Homicides & Other External Causes	5	9.65	51.8	16.8	120.9

* significant at 5% level
** significant at 1% level

No. of employees = 3,328
Person-years = 60,612

Table 3
Cause-specific mortality of male employees at the Torrance refinery

Cause of death	OBS	EXP	SMR	95% Confidence limits Lower	Upper
All Causes of Death	694	843.36	82.3 **	76.3	88.6
All Malignant Neoplasms	157	196.22	80.0 **	68.0	93.6
Cancer of Buccal Cavity & Pharynx	3	4.90	61.2	12.6	178.9
Cancer of Digestive Organs & Peritoneum	34	48.34	70.3 *	48.7	98.3
Cancer of Esophagus	3	4.99	60.1	12.4	175.5
Cancer of Stomach	5	7.13	70.1	22.8	163.7
Cancer of Large Intestine	11	17.76	61.9	30.9	110.8
Cancer of Rectum	2	4.15	48.2	5.8	174.0
Cancer of Biliary Passages & Liver	1	4.16	24.0	0.6	133.8
Cancer of Pancreas	12	9.76	122.9	63.5	214.8
Cancer of All Other Digestive Organs	0	1.36	0.0	0.0	271.2
Cancer of Respiratory System	52	70.36	73.9 *	55.2	96.9
Cancer of Larynx	0	2.53	0.0	0.0	145.6
Cancer of Bronchus, Trachea, Lung	51	67.10	76.0 *	56.6	99.9
Cancer of All Other Respiratory	1	0.71	139.9	3.5	779.5
Cancer of Breast	1	0.24	418.7	10.5	2332.9
Cancer of Prostate	18	18.98	94.8	56.2	149.9
Cancer of Testes and Other Male Genital Organs	0	0.54	0.0	0.0	678.7
Cancer of Kidney	3	4.70	63.8	13.2	186.5
Cancer of Bladder and Other Urinary Organs	2	5.69	35.2	4.3	127.1
Malignant Melanoma of Skin	4	2.66	150.4	41.0	385.2
Cancer of Eye	1	0.12	818.6	20.5	4561.3
Cancer of Central Nervous System	6	4.76	126.0	46.2	274.2
Cancer of Thyroid & Other Endocrine Glands	0	0.53	0.0	0.0	693.1
Cancer of Bone	0	0.52	0.0	0.0	706.1
Cancer of All Lymphatic, Haematopoietic Tissue	19	18.18	104.5	62.9	163.2
Lymphosarcoma & Reticulosarcoma	1	2.07	48.2	1.2	268.7
Hodgkins Disease	1	1.10	90.8	2.3	505.9
Leukemia & Aleukemia	5	7.19	69.5	22.6	162.2
Cancer of All Other Lymphopoietic Tissue	12	7.82	153.5	79.3	268.2
All Other Malignant Neoplasms	14	14.87	94.1	51.5	157.9
Benign Neoplasms	0	2.04	0.0	0.0	180.8
Diabetes Mellitus	10	13.82	72.4	34.7	133.1
Cerebrovascular Disease	38	49.72	76.4	54.1	104.9
All Heart Disease	287	322.42	89.0 *	79.0	99.9
Rheumatic Heart Disease	5	4.47	111.7	36.3	260.7
Ischemic Heart Disease	247	280.81	88.0 *	77.3	99.6
Chronic Endocard. Dis.; Other Myocard. Insuff.	1	11.87	8.4 **	0.2	46.9
Hypertension with Heart Disease	5	6.42	77.9	25.3	181.8
All Other Heart Disease	29	44.19	65.6 *	44.0	94.3
Hypertension w/o Heart Disease	3	2.24	133.8	27.6	390.9
Non-malignant Respiratory Disease	55	68.45	80.3	60.5	104.6
Influenza & Pneumonia	15	24.96	60.1 *	33.6	99.1
Bronchitis, Emphysema, Asthma	12	14.01	85.6	44.2	149.6
Bronchitis	3	2.25	133.1	27.5	389.0
Emphysema	9	10.84	83.0	38.0	157.6
Asthma	0	0.96	0.0	0.0	386.1
Other Non-malignant Respiratory Disease	28	30.85	90.8	60.3	131.2
Ulcer of Stomach & Duodenum	0	3.31	0.0	0.0	111.5
Cirrhosis of Liver	19	16.86	112.7	67.8	176.0
Nephritis & Nephrosis	5	4.24	117.9	38.3	275.1
All External Causes of Death	58	63.69	91.1	69.1	117.7
Accidents	37	38.13	97.0	68.3	133.8
Motor Vehicle Accidents	22	17.18	128.1	80.3	193.9
All Other Accidents	15	21.10	71.1	39.8	117.2
Suicides	16	15.41	103.8	59.3	168.6
Homicides & Other External Causes	5	9.35	53.5	17.4	124.8

* significant at 5% level
** significant at 1% level

No. of employees = 2,965
Person-years = 55,984

Table 4

Cause-specific mortality of male employees at the Torrance refinery by length of employment

Cause of death	<10 years OBS	<10 years SMR	10-29 years OBS	10-29 years SMR	30+ years OBS	30+ years SMR
All causes	128	72.7 **	425	84.2 **	141	86.8
All malignant neoplasms	38	96.5	87	75.6 **	32	76.6
Cancer of buccal cavity & pharynx	0	0.0	3	102.7	0	0.0
Cancer of digestive organs & peritoneum	8	87.4	19	65.5	7	68.9
Cancer of esophagus	0	0.0	2	70.1	1	97.4
Cancer of stomach	1	76.8	4	90.5	0	0.0
Cancer of large intestine	3	93.6	5	47.0	3	76.8
Cancer of rectum	0	0.0	0	0.0	2	241.6
Cancer of biliary passages & liver	1	111.2	0	0.0	0	0.0
Cancer of pancreas	3	160.2	8	137.2	1	48.6
Cancer of all other digestive organs	0	0.0	0	0.0	0	0.0
Cancer of respiratory system	13	90.2	29	71.4	10	65.2
Cancer of larynx	0	0.0	0	0.0	0	0.0
Cancer of bronchus, trachea & lung	12	87.3	29	75.0	10	68.1
Cancer of breast	0	0.0	1	694.2	0	0.0
Cancer of prostate	2	83.5	10	83.8	6	129.2
Cancer of kidney	1	95.9	2	74.2	0	0.0
Cancer of bladder & other urinary organs	1	122.8	1	27.9	0	0.0
Malignant melanoma of skin	1	115.6	3	224.1	0	0.0
Cancer of central nervous system	2	142.1	3	117.5	1	124.7
Cancer of lymphatic & hematopoietic tissues	6	141.9	11	106.3	2	55.6
Lymphosarcoma & reticulosarcoma	1	244.4	0	0.0	0	0.0
Hodgkin's disease	1	258.1	0	0.0	0	0.0
Leukemia	1	62.3	4	96.6	0	0.0
Cancer of other lymphopoietic tissue	3	164.1	7	163.5	2	117.2
Benign neoplasms	0	0.0	0	0.0	0	0.0
Diabetes mellitus	3	103.0	5	61.7	2	71.3
Cerebrovascular disease	3	42.9	22	67.5	13	128.4
All heart disease	38	70.1 *	192	94.3	57	88.1
Ischemic heart disease	25	54.9 **	171	95.6	51	90.4
Nonmalignant respiratory disease	8	76.8	34	79.4	13	85.5
Influenza & pneumonia	0	0.0 *	12	74.5	3	58.8
Bronchitis, emphysema & asthma	1	51.3	6	65.6	5	171.6
Other non-malignant respiratory disease	7	141.9	16	86.8	5	66.8
Cirrhosis of liver	1	19.6	16	169.6	2	86.4
All external causes of death	25	82.7	26	93.0	7	127.0
Accidents	15	87.9	19	108.6	3	83.8
Motor vehicle accidents	9	101.6	11	155.9	2	157.8
All other accidents	6	72.6	8	76.2	1	42.8
Suicides	6	86.8	6	86.3	4	258.2
Homicides & other external causes	4	66.7	1	33.3	0	0.0
Number of employees	2,452		1,393		283	
Person-years	28,430		23,073		4,482	

* significant at the 5% level; ** significant at the 1% level

Table 5

Cause-specific mortality of male employees at the Torrance refinery by time since first employment

Cause of death	<20 years OBS	<20 years SMR	20-39 years OBS	20-39 years SMR	40+ years OBS	40+ years SMR
All causes	84	59.5 **	322	83.3 **	288	91.2
All malignant neoplasms	20	78.4	77	79.1 *	60	81.7
Cancer of buccal cavity & pharynx	0	0.0	3	108.2	0	0.0
Cancer of digestive organs & peritoneum	2	32.3	19	77.7	13	73.5
Cancer of esophagus	0	0.0	2	76.1	1	62.8
Cancer of stomach	1	93.6	3	81.0	1	42.5
Cancer of large intestine	1	53.8	5	58.1	5	68.6
Cancer of rectum	0	0.0	1	44.7	1	74.2
Cancer of biliary passages & liver	0	0.0	1	52.2	0	0.0
Cancer of pancreas	0	0.0	7	137.5	5	145.7
Cancer of all other digestive organs	0	0.0	0	0.0	0	0.0
Cancer of respiratory system	6	68.9	27	71.8	19	79.0
Cancer of larynx	0	0.0	0	0.0	0	0.0
Cancer of bronchus, trachea & lung	5	61.0	27	75.4	19	82.3
Cancer of breast	0	0.0	1	831.1	0	0.0
Cancer of prostate	1	140.4	4	57.7	13	114.7
Cancer of kidney	2	286.9	1	41.1	0	0.0
Cancer of bladder & other urinary organs	0	0.0	1	38.2	1	37.5
Malignant melanoma of skin	0	0.0	4	327.5	0	0.0
Cancer of central nervous system	0	0.0	6	245.4	0	0.0
Cancer of lymphatic & hematopoietic tissues	8	248.4 *	4	48.1	7	105.5
Lymphosarcoma & reticulosarcoma	0	0.0	1	82.8	0	0.0
Hodgkin's disease	1	216.1	0	0.0	0	0.0
Leukemia	2	166.3	0	0.0	3	108.8
Cancer of other lymphopoietic tissue	5	458.6 *	3	88.2	4	120.3
Benign neoplasms	0	0.0	0	0.0	0	0.0
Diabetes mellitus	1	46.5	3	48.4	6	109.6
Cerebrovascular disease	2	40.1	18	81.2	18	79.7
All heart disease	26	65.0 *	139	87.8	122	98.3
Ischemic heart disease	22	65.5 *	119	83.8	106	100.7
Nonmalignant respiratory disease	2	35.2	21	76.9	32	90.2
Influenza & pneumonia	0	0.0	5	59.3	10	71.4
Bronchitis, emphysema & asthma	0	0.0	5	67.2	7	136.5
Other non-malignant respiratory disease	2	109.1	11	93.5	15	86.9
Cirrhosis of liver	0	0.0 *	18	195.5 *	1	40.0
All external causes of death	25	73.9	22	103.0	11	129.8
Accidents	17	89.2	14	106.4	6	101.6
Motor vehicle accidents	12	119.9	6	110.7	4	228.4
All other accidents	5	54.9	8	102.8	2	47.5
Suicides	5	67.5	6	103.6	5	225.7
Homicides & other external causes	3	43.7	2	93.0	0	0.0
Number of employees	2,795		1,599		674	
Person-years	31,161		19,640		5,182	

* significant at the 5% level; ** significant at the 1% level

Table 6
Cause-specific mortality of male maintenance employees at the Torrance refinery

Cause of death	OBS	EXP	SMR	95% Confidence limits Lower	Upper
All Causes of Death	301	313.04	96.2	85.6	107.7
All Malignant Neoplasms	67	73.62	91.0	70.5	115.6
Cancer of Buccal Cavity & Pharynx	1	1.89	53.0	1.3	295.2
Cancer of Digestive Organs & Peritoneum	18	18.06	99.6	59.1	157.5
Cancer of Esophagus	3	1.93	155.5	32.1	454.4
Cancer of Stomach	2	2.68	74.7	9.0	270.0
Cancer of Large Intestine	6	6.55	91.6	33.6	199.5
Cancer of Rectum	1	1.54	64.9	1.6	361.6
Cancer of Biliary Passages & Liver	0	1.57	0.0	0.0	235.7
Cancer of Pancreas	6	3.67	163.7	60.1	356.3
Cancer of All Other Digestive Organs	0	0.51	0.0	0.0	725.5
Cancer of Respiratory System	22	26.74	82.3	51.6	124.6
Cancer of Larynx	0	0.96	0.0	0.0	382.7
Cancer of Bronchus, Trachea, Lung	22	25.50	86.3	54.1	130.6
Cancer of All Other Respiratory	0	0.27	0.0	0.0	1347.7
Cancer of Breast	0	0.09	0.0	0.0	4112.6
Cancer of Prostate	7	6.59	106.3	42.7	219.0
Cancer of Testes and Other Male Genital Organs	0	0.23	0.0	0.0	1616.9
Cancer of Kidney	1	1.79	55.7	1.4	310.6
Cancer of Bladder and Other Urinary Organs	1	2.03	49.3	1.2	274.5
Malignant Melanoma of Skin	3	1.06	282.9	58.4	826.8
Cancer of Eye	1	0.05	2172.8	54.3	12107.0
Cancer of Central Nervous System	2	1.89	106.1	12.8	383.1
Cancer of Thyroid & Other Endocrine Glands	0	0.21	0.0	0.0	1793.7
Cancer of Bone	0	0.20	0.0	0.0	1844.4
Cancer of All Lymphatic, Haematopoietic Tissue	5	6.87	72.8	23.6	169.8
Lymphosarcoma & Reticulosarcoma	0	0.79	0.0	0.0	465.8
Hodgkins Disease	0	0.45	0.0	0.0	819.9
Leukemia & Aleukemia	2	2.70	74.2	9.0	268.0
Cancer of All Other Lymphopoietic Tissue	3	2.93	102.2	21.1	298.7
All Other Malignant Neoplasms	6	5.62	106.7	39.2	232.3
Benign Neoplasms	0	0.76	0.0	0.0	482.7
Diabetes Mellitus	3	5.16	58.2	12.0	170.0
Cerebrovascular Disease	15	17.76	84.5	47.3	139.3
All Heart Disease	125	117.84	106.1	88.3	126.4
Rheumatic Heart Disease	0	1.70	0.0	0.0	216.5
Ischemic Heart Disease	105	102.54	102.4	83.8	124.0
Chronic Endocard. Dis.; Other Myocard. Insuff.	1	4.08	24.5	0.6	136.5
Hypertension with Heart Disease	3	2.41	124.5	25.7	363.8
All Other Heart Disease	16	16.30	98.2	56.1	159.4
Hypertension w/o Heart Disease	2	0.82	243.4	29.5	879.3
Non-malignant Respiratory Disease	18	24.22	74.3	44.0	117.5
Influenza & Pneumonia	5	8.66	57.7	18.7	134.8
Bronchitis, Emphysema, Asthma	4	5.06	79.1	21.6	202.5
Bronchitis	0	0.80	0.0	0.0	458.6
Emphysema	4	3.90	102.7	28.0	262.8
Asthma	0	0.36	0.0	0.0	1012.7
Other Non-malignant Respiratory Disease	9	10.97	82.1	37.5	155.8
Ulcer of Stomach & Duodenum	0	1.21	0.0	0.0	303.9
Cirrhosis of Liver	13	6.84	190.1 *	101.2	325.1
Nephritis & Nephrosis	0	1.54	0.0	0.0	239.2
All External Causes of Death	34	26.34	129.1	89.4	180.4
Accidents	17	15.67	108.5	63.2	173.7
Motor Vehicle Accidents	12	7.24	165.7	85.6	289.4
All Other Accidents	5	8.49	58.9	19.1	137.5
Suicides	13	6.23	208.6 *	111.1	356.7
Homicides & Other External Causes	4	4.10	97.6	26.6	249.9

* significant at 5% level
** significant at 1% level

No. of employees = 1,075
Person-years = 23,419

Table 7
Cause-specific mortality of male process employees at the Torrance refinery

Cause of death	OBS	EXP	SMR	95% Confidence limits Lower	Upper
All Causes of Death	219	269.45	81.3 **	70.9	92.8
All Malignant Neoplasms	42	62.44	67.3 **	48.5	90.9
Cancer of Buccal Cavity & Pharynx	0	1.59	0.0	0.0	232.3
Cancer of Digestive Organs & Peritoneum	13	15.24	85.3	45.4	145.8
Cancer of Esophagus	1	1.61	62.1	1.6	346.3
Cancer of Stomach	3	2.22	135.3	27.9	395.4
Cancer of Large Intestine	3	5.60	53.6	11.1	156.6
Cancer of Rectum	1	1.29	77.5	1.9	432.1
Cancer of Biliary Passages & Liver	0	1.35	0.0	0.0	273.6
Cancer of Pancreas	5	3.08	162.3	52.7	378.8
Cancer of All Other Digestive Organs	0	0.42	0.0	0.0	872.0
Cancer of Respiratory System	10	22.48	44.5 **	21.3	81.8
Cancer of Larynx	0	0.81	0.0	0.0	455.3
Cancer of Bronchus, Trachea, Lung	10	21.43	46.7 **	22.4	85.8
Cancer of All Other Respiratory	0	0.23	0.0	0.0	1592.5
Cancer of Breast	0	0.08	0.0	0.0	4883.0
Cancer of Prostate	3	5.82	51.5	10.6	150.6
Cancer of Testes and Other Male Genital Organs	0	0.19	0.0	0.0	1933.0
Cancer of Kidney	2	1.51	132.7	16.1	479.5
Cancer of Bladder and Other Urinary Organs	0	1.75	0.0	0.0	211.1
Malignant Melanoma of Skin	1	0.89	112.5	2.8	627.0
Cancer of Eye	0	0.04	0.0	0.0	9620.5
Cancer of Central Nervous System	2	1.58	126.4	15.3	456.5
Cancer of Thyroid & Other Endocrine Glands	0	0.17	0.0	0.0	2142.1
Cancer of Bone	0	0.17	0.0	0.0	2166.8
Cancer of All Lymphatic, Haematopoietic Tissue	7	5.88	119.0	47.8	245.1
Lymphosarcoma & Reticulosarcoma	0	0.65	0.0	0.0	564.4
Hodgkins Disease	1	0.37	267.8	6.7	1492.1
Leukemia & Aleukemia	2	2.32	86.4	10.5	312.1
Cancer of All Other Lymphopoietic Tissue	4	2.54	157.3	42.9	402.7
All Other Malignant Neoplasms	4	4.78	83.6	22.8	214.2
Benign Neoplasms	0	0.66	0.0	0.0	562.7
Diabetes Mellitus	0	4.41	0.0 *	0.0	83.6
Cerebrovascular Disease	14	15.03	93.2	50.9	156.3
All Heart Disease	92	100.22	91.8	74.0	112.6
Rheumatic Heart Disease	1	1.42	70.6	1.8	393.5
Ischemic Heart Disease	78	86.86	89.8	71.0	112.1
Chronic Endocard. Dis.; Other Myocard. Insuff.	0	3.73	0.0 *	0.0	98.9
Hypertension with Heart Disease	0	2.07	0.0	0.0	178.3
All Other Heart Disease	13	14.26	91.2	48.5	155.9
Hypertension w/o Heart Disease	0	0.69	0.0	0.0	532.1
Non-malignant Respiratory Disease	18	21.34	84.4	50.0	133.3
Influenza & Pneumonia	4	7.67	52.1	14.2	133.5
Bronchitis, Emphysema, Asthma	7	4.29	163.2	65.6	336.2
Bronchitis	2	0.68	292.7	35.4	1057.5
Emphysema	5	3.30	151.6	49.2	353.7
Asthma	0	0.31	0.0	0.0	1178.8
Other Non-malignant Respiratory Disease	7	9.80	71.4	28.7	147.1
Ulcer of Stomach & Duodenum	0	1.01	0.0	0.0	364.6
Cirrhosis of Liver	8	5.71	140.1	60.5	276.1
Nephritis & Nephrosis	3	1.33	226.0	46.6	660.4
All External Causes of Death	25	23.70	105.5	68.3	155.7
Accidents	17	13.89	122.4	71.3	195.9
Motor Vehicle Accidents	12	6.48	185.3	95.8	323.7
All Other Accidents	5	7.47	67.0	21.7	156.2
Suicides	6	5.60	107.2	39.4	233.4
Homicides & Other External Causes	2	3.98	50.3	6.1	181.6

* significant at 5% level
** significant at 1% level

No. of employees = 1,069
Person-years = 20,815

Table 8

Mortality from lymphohematopoietic cancers of male employees at the Torrance refinery

Total cohort

Cause of death	OBS	EXP	SMR	95% CI
Acute lymphoid leukemia	0	0.36	0.0	(0.0-1035.2)
Chronic lymphoid leukemia	1	1.34	74.4	(1.9-414.3)
Acute myeloid leukemia	1	2.20	45.4	(1.1-252.8)
Chronic myeloid leukemia	2	1.02	195.6	(23.7-706.6)
Multiple myeloma	4	3.28	122.1	(33.3-312.5)
Non-Hodgkin's lymphoma	9	7.42	121.4	(55.5-230.4)

Maintenance

Cause of death	OBS	EXP	SMR	95% CI
Acute lymphoid leukemia	0	0.14	0.0	(0.0-2721.8)
Chronic lymphoid leukemia	0	0.48	0.0	(0.0-769.7)
Acute myeloid leukemia	0	0.83	0.0	(0.0-443.0)
Chronic myeloid leukemia	1	0.39	253.6	(6.3-1412.8)
Multiple myeloma	0	1.22	0.0	(0.0-302.4)
Non-Hodgkin's lymphoma	2	2.81	71.2	(8.6-257.2)

Process

Cause of death	OBS	EXP	SMR	95% CI
Acute lymphoid leukemia				(0.0-3042.5)
Chronic lymphoid leukemia				(6.0-1340.6)
Acute myeloid leukemia				(3.5-776.5)
Chronic myeloid leukemia				(0.0-1083.8)
Multiple myeloma				(2.4-539.2)
Non-Hodgkin's lymphoma				(45.3-425.4)

Tables 8-9

DCMAP. total. dat ?

DCMAP. maint. dat ?

DCMAP. proc. dat ?

Table 9
Mortality from lymphohematopoietic cancers of male employees at the Torrance refinery by length of employment and time since hire

Length of employment	<10 years			10-29 years			30+ years		
Cause of death	OBS	SMR	95% CI	OBS	SMR	95% CI	OBS	SMR	95% CI
Acute lymphoid leukemia	0	0.0	(0.0-3332.3)	0	0.0	(0.0-1989.3)	0	0.0	(0.0-6125.3)
Chronic lymphoid leukemia	0	0.0	(0.0-1869.5)	1	120.5	(3.0-671.6)	0	0.0	(0.0-1160.3)
Acute myeloid leukemia	0	0.0	(0.0-706.9)	1	80.6	(2.0-449.4)	0	0.0	(0.0-834.1)
Chronic myeloid leukemia	1	344.2	(8.6-1918.0)	1	179.3	(4.5-999.3)	0	0.0	(0.0-2115.9)
Multiple myeloma	1	166.6	(4.2-928.1)	1	51.1	(1.3-284.7)	2	277.9	(33.6-1003.9)
Non-Hodgkin's lymphoma	4	225.9	(61.1-578.5)	5	119.4	(38.8-278.7)	0	0.0	(0.0-253.0)

Time since hire	<20 years			20-39 years			40+ years		
Cause of death	OBS	SMR	95% CI	OBS	SMR	95% CI	OBS	SMR	95% CI
Acute lymphoid leukemia	0	0.0	(0.0-3613.3)	0	0.0	(0.0-2892.9)	0	0.0	(0.0-2910.3)
Chronic lymphoid leukemia	0	0.0	(0.0-4546.3)	0	0.0	(0.0-628.1)	1	147.8	(3.7-823.8)
Acute myeloid leukemia	0	0.0	(0.0-958.5)	0	0.0	(0.0-357.7)	1	126.9	(3.2-707.2)
Chronic myeloid leukemia	2	729.5	(93.1-2780.0)	0	0.0	(0.0-861.3)	0	0.0	(0.0-1103.6)
Multiple myeloma	1	271.3	(6.8-1511.6)	2	125.3	(15.2-452.7)	1	76.2	(1.9-424.6)
Non-Hodgkin's lymphoma	4	298.3	(81.3-763.9)	2	57.9	(7.0-209.1)	3	114.5	(23.6-334.6)