

A FOLLOW-UP STUDY
OF PETROLEUM REFINERY WORKERS

Philip Cole, M.D.
Elizabeth Delzell, S.D.
Chansuda Wongsrichanalai, M.D.

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EXECUTIVE SUMMARY

This study evaluated the mortality experience of 10,718 employees of the Shell Oil Company Wood River Refinery. The subjects were all employees who had worked at the refinery for at least six months before December 31, 1983, and who were employed in 1940 or later if staff or in 1942 or later if hourly. We determined the vital status of 94% of the cohort. Of the 2,925 employees who were known to be deceased, death certificates were available for 2,774 (95%). We compared the overall and cause-specific observed numbers of deaths among the refinery workers with the numbers expected on the basis of US general population mortality rates.

Among the 9,484 white men included in the study, mortality rates for all causes and for most major cause of death categories were substantially lower than those of white men in the US general population. Overall, there were 2,874 observed deaths, compared with 3,568 expected (SMR=0.8). The SMR for all cancers combined was 0.9 (95% confidence interval: 0.8-1.0). The generally favorable mortality experience of the white men occurred among long-term employees, and it was still evident 40 years after first hire. These results are similar to those of most previous studies of petroleum refinery workers, including an earlier investigation of Wood River Refinery employees.

The only statistically significant results for white men for specific cancers were: (1) a 60% excess of leukemia, based on 44 observed and 28.2 expected deaths; (2) a 70% deficit of deaths

from cancer of the buccal cavity and pharynx, based on 6 observed and 22.5 expected deaths; and (3) a 60% deficit of deaths from cancer of the liver, based on six observed and 15.5 expected deaths. There were small excesses of skin cancer (SMR=1.2), Hodgkin's disease (SMR=1.2) and cancer of other lymphatic and hematopoietic tissues (SMR=1.1), but none of these was statistically significant. There were no excesses of certain cancers found to be increased in other groups of refinery workers, including cancers of the stomach, pancreas, lung, bladder, kidney and brain.

The overall excess of leukemia began in the 1950s (10/3.7; SMR=2.7) and persisted until 1980. In 1980-1984, there was no excess (6/5.7; SMR=1.1). Analyses of leukemia mortality by cell type, period of death and period of hire revealed several interesting patterns. For lymphocytic leukemia, there was an excess among deaths occurring before 1970 (11/3.1; SMR=3.5) but no excess in 1970-1984 (5/4.5; SMR=1.1). Lymphocytic leukemia was increased both among men hired before 1940 and among men hired in 1940 or later. In contrast, for myelocytic leukemia, there was a deficit before 1970 (2/4.8; SMR=0.4) and an excess, due entirely to acute myelocytic leukemia (12/5.0; SMR=2.4) in 1970-1984. Furthermore, the acute myelocytic leukemia excess was limited to men hired in 1940 or later. Monocytic leukemia was increased from 1950 through 1979 (6/1.05; SMR=5.7) and did not appear to be related to period of hire.

If these patterns are real and not due to misclassification of leukemias by cell type, they have several implications. It is

possible that the restriction of the acute myelocytic leukemia excess to men hired in 1940 or later is related to process changes which occurred at the refinery after 1940. These changes resulted in an increased percentage of benzene in certain refinery streams. However, it is not known whether there was a concomitant increase in workers' exposure to benzene. The fact that there was an apparent excess of lymphocytic, but not myelocytic, leukemia among men hired before 1940 suggests that some exposure other than benzene was responsible. This study did not assess the detailed job histories or exposures of workers at the refinery. Therefore, it does not provide any direct information which would allow us to determine if the overall or cell type-specific leukemia excesses are linked to specific jobs or to exposure to benzene or other chemicals.

Future observation of cell type-specific leukemia mortality will be necessary to confirm the apparent decrease in the lymphocytic and monocytic leukemia excesses and to determine if the acute myelocytic leukemia excess persists among Wood River Refinery employees. Additional work will also be required to evaluate the possible association of lymphocytic, myelocytic and monocytic leukemias with benzene and other chemicals at the refinery.

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INTRODUCTION

This report describes the mortality experience of employees of the Shell Oil Company Wood River Refinery in Roxana, Illinois. The refinery, which has been in operation since 1918, is a manufacturing complex whose operations include crude oil refining and production of gasoline, aviation fuel, diesel fuel, lubricating oils, asphalt and various petrochemicals, including benzene.

Both a retrospective follow-up study (RFS) and a case-control study of leukemia among Wood River Refinery workers have been conducted (1,2). The RFS examined the cause-specific mortality experience of 3,976 white men who had worked at the refinery for at least one day from January 1, 1973, through December 31, 1982, or who had retired from the refinery before 1973 and were alive on January 1, 1973 (1). The employees included in the study had mortality rates which were lower than those of United States (US) white men for all causes, all cancers and all specific major organ system diseases. However, there was a two-fold increase in leukemia deaths: the standardized mortality ratio (SMR) for leukemia was 2.13, with a 95% confidence interval (CI) of 1.17 to 3.58, based on 14 observed and 6.6 expected deaths. Eight of the 14 men who died of leukemia had acute myelocytic leukemia, and the SMR for this cell type was 3.94 (95% CI, 1.72-7.88).

The findings pertaining to leukemia at the Wood River Refinery are unusual in two respects. First, eight earlier studies of refinery workers have reported inconsistent results for leukemia (3-10). Three of these studies found an excess, with estimated rate ratios of 1.14 (3), 1.18 (4) and 1.73 (5), and only the latter rate ratio was statistically significant at the 0.05 probability level. Thus, the leukemia excess among Wood River Refinery employees is the largest reported in the published literature to date. Second, the study of Wood River Refinery employees is the only published report of an excess of acute myelocytic leukemia among oil refinery workers. Because benzene is present in petroleum refineries and is generally recognized as a cause of acute myelocytic leukemia (11), the observation of an excess of this cell type was of particular interest and was investigated further in a nested case-control study (2). This study evaluated the association of leukemia with jobs, departments and estimated benzene levels among workers at the refinery. No specific job or department could be identified as responsible for the leukemia excess. Comparison of the benzene exposure levels of cases and controls did not indicate any association with benzene.

The purpose of the present investigation was to examine further the overall and cause-specific mortality patterns of employees at the Wood River Refinery. The study is an expansion

of the previous RFS, in terms of both the observation period and the number of workers included. It is more than twice as large as the earlier investigation, and it covers a longer follow-up period, 1940 through 1984. It also examines in more detail the effects on overall mortality and leukemia mortality of certain employment features such as duration of work, calendar period of work and potential exposure to refinery chemicals, as indicated by hourly versus staff (salaried) payroll classification and type of staff position.

METHODS

Definition of study groups

The study included all employees who met the following criteria:

- (a) employed for at least six months before December 31, 1983;
- (b) hourly and employed at any time during 1942 through 1983; and
- (c) staff and employed at any time during 1940 through 1983.

Employment records of hourly workers who terminated before 1942 and of staff workers who terminated before 1940 were not routinely available; therefore, we did not include these employees in the study. As mentioned previously, the present investigation included most of the workers who were part of the previous RFS.

We identified the following groups of employees and conducted all analyses separately for these groups: (a) white men and men of unknown race (these groups are referred to hereafter as "white men"); (b) white women; and (c) black men. For white men, we also defined two mutually exclusive subgroups based on payroll classification:

- (a) "ever hourly" employees comprised men who had ever been hourly, including men who had started as hourly and then transferred to staff positions;
- (b) "always staff" employees included men who held staff positions and who had never been hourly.

We further classified the always staff employees as:

- (a) ever employed in production-related (PR) jobs and
- (b) employed only in nonproduction-related (NPR) jobs.

We did not consider strike duty in designating staff workers as PR or NPR. Appendix A provides further information on the classification of PR and NPR jobs.

Sources of identifying and employment information

We sought the following information for all workers included in the study: name, social security number, company identification number, gender, race, birth date, dates of first employment and of termination at the refinery, employment status (active, retired or terminated), payroll classification (hourly or staff), type of staff job (PR or NPR), date of death and state of death. Sources used to

obtain these data are described below. The figure summarizes the cohort identification and data sources.

We used a computer file developed for the previous RFS to obtain most of the data for employees who terminated after 1972 or who were retired and alive as of January 1, 1973. The file was modified to include women and nonwhites and was updated through January, 1985. The updated version contained information on 4,585 employees.

Both the original and the updated files of the previous RFS lacked certain job history data needed for the present study, including the following: precise dates of beginning and terminating work at the Wood River Refinery; last payroll classification; information on whether or not staff employees had ever been on the hourly payroll at the Wood River Refinery; and, if ever hourly, the last date hourly.

Employment dates on the computer files of the previous study were uncertain for two reasons. First, the files contained the "equated date" of employment rather than the actual hire date at the Wood River Refinery for many employees. The equated date is the hire date, adjusted for periods of unemployment. For staff employees, it refers to the date of starting work at the Shell Oil Company, not at a particular facility. Therefore, the difference between the date of hire at Wood River and the equated date ranges from zero to many years. This difference usually would be larger for staff employees, among whom transfers from location to location are common, than for hourly workers.

Second, the termination dates were the dates of termination with the Shell Oil Company and did not necessarily specify the date on which employees left the Wood River Refinery. As with equated dates, differences between the Shell Company termination date and the termination date at Wood River tend to occur among staff but not among hourly workers.

To verify employment dates and to obtain additional job history information on staff workers included in the previous study, we obtained additional work records from the refinery and from the Shell Corporate Office. From these records, we abstracted information on hire date; termination date; employment status; last payroll classification; whether or not the employee ever had been on the hourly payroll; if so, the last date on the hourly payroll; and type of staff job (PR or NPR). We did not attempt to verify the employment dates of all hourly workers included in the original RFS. It is likely that errors in their employment dates are few and small.

We identified employees who were not included in the previous RFS and obtained information on them from personnel records stored at the refinery. These records are described below.

Employee Service Records (ESRs): ESRs were available for hourly workers who terminated in 1942-1965. The ESRs usually contained all of the information sought except race.

Personnel Files: Personnel files were available for hourly workers who terminated from 1955 through 1965 and for hourly workers who retired from 1942 through 1965. These files contained most of the information sought but did not provide job history information in as much detail as ESRs.

Consolidated Files: Since 1966, hourly workers' ESRs and personnel files have been combined in a single, "consolidated" record. These were available for hourly workers who terminated or retired from 1966 to 1976. Staff workers have always had consolidated files, and the files were available for those who terminated from 1940 to 1976.

Pensioners' Records: Pensioners' records were available for some workers who were active pensioners in 1946-1972. These records provided essentially the same information as consolidated files.

We prepared record abstracts for all available ESRs, personnel files, consolidated files and pensioners' records for workers who terminated or retired before 1973 and for some who terminated after 1973. Appendix B displays the record abstract form. We completed 10,348 record abstracts (employees who worked fewer than six months included) and developed these into a computer file, referred to hereafter as the "abstract file."

One hundred seventy-seven individuals had more than one record on the abstract file. We merged these duplicate records, using procedures which maximized data completeness and accuracy. For example, personnel file data were useful

in supplying information on race, which was not usually available from ESRs. Pensioners' records were useful in supplying data on race and date of death for a small number of cohort members. The abstract file contained 10,066 eligible subjects after the 177 pairs of record abstracts were merged and after exclusion of workers with unknown SSN (N=39), staff workers who terminated before 1940, hourly workers who terminated before 1942 (N=19) and employees with missing birth or employment dates (N=47). We then combined the records of these 10,066 individuals with records in the updated file from the previous RFS and merged the duplicate records of 1,497 individuals who appeared on both files. Appendix C provides additional documentation of the merging process.

After combining these files, the total number of subjects was 13,154. Of these, 2,400 who had worked for fewer than six months were removed from the cohort. This resulted in a final study size of 10,754, including 9,484 white men, 1,060 women and 210 black men. Thirty-six of the women were known to be black and were excluded, resulting in a total of 1,024 "white" women. Appendix G describes the results of data analysis for the 2,042 white men and the 286 white women who worked at the refinery for fewer than six months.

We used several additional sources of information to check the completeness of cohort identification. These records included the Wood River Refinery "green books" (lists of names of employees who terminated from 1940-1983 with hire date, and reason for termination); lists of hourly and staff workers active

as of January, 1985; and note books containing data on Wood River research laboratory workers during 1950-1975. By crosschecking the names compiled from these three additional sources with the abstract and previous RFS files, we found that records were not available for 261 employees.

Ascertainment of vital status

We used company, Social Security Administration (SSA) and National Death Index (NDI) records to determine the vital status of subjects. Initially, active workers and pensioners were followed using records available at the Wood River Refinery and the Head Office. We used these records to identify workers who were active either at the Wood River Refinery or at other Shell locations as of January 1, 1985; to identify Shell pensioners who were alive as of the same date; and to identify deaths among active workers and pensioners.

We submitted to the SSA a list consisting of the 10,272 cohort members who were not active as of January 1, 1985, and who did not have a death certificate on file. The SSA provided information on deaths that occurred through 1984 and identified individuals assumed to be alive at the end of 1983. The SSA search identified 2,479 individuals as deceased, 6,904 as alive and 889 with unknown vital status.

To complete vital status ascertainment, we submitted a total of 937 names to the NDI, including the names of workers whose status could not be determined by Company or SSA records and of workers whom the SSA identified as having died after 1978 but

whose death certificates were not located initially. Appendix D describes the vital status ascertainment procedures in more detail.

Death certificate acquisition

The total number of deaths identified was 3,451. This includes 526 deaths among subjects employed for fewer than six months. We obtained 711 death certificates from the Shell Corporate Office. In addition, for 233 employees identified as deceased during record abstraction, we located death certificates at the refinery or obtained them from Illinois or Missouri vital records offices.

For the additional 2,479 deaths identified by the SSA, we requested certificates from the vital records offices of 42 states. Of the 2,479 decedents identified by the SSA, we found death certificates for 2,253. Of the 226 (9%) not located, 48 died after 1978. We submitted these 48 names to the NDI, together with those of workers who were lost to follow-up. The NDI was able to confirm 44 of the deaths, and we obtained death certificates for 40 of them. The NDI identified 28 additional deaths, and we located death certificates for 27 of these. The total number of death certificates located was 3,267 (95%) of the 3,451 reported deaths. Among workers employed for at least six months, the total number of death certificates located was 2,771 (95%) of the 2,925 reported deaths.

A nosologist coded the underlying cause of death according to the Eighth Revision of the International Classification of Diseases, using coding rules in effect at the time of death. A contributing cause of death was also coded if it was a blood disease or a cancer. Appendix E describes the nosologic coding of leukemia.

Data analysis

We compared the mortality experience of each of the study groups with that of the appropriate segment of the US population, using the SMR as the measure of association. In this report, the SMR is expressed as the ratio of the observed to the expected number of deaths.

To obtain the expected numbers of deaths for the SMR, we multiplied the age-, gender-, race-, calendar time-, and cause-specific mortality rates of the US general population by the corresponding number of person-years (PY) of observation of the refinery workers. We computed PY of observation by summing the total years of follow-up of workers as they passed through each five-year age group and calendar period. For staff workers, follow-up began 6 months after the first date of employment or on January 1, 1940, for employees hired more than six months before. For hourly workers, follow-up began six months after the first date of employment or on January 1, 1942, for employees hired more than six months before 1942. Observation continued until death or until January 1, 1985. For those lost to follow-up, PY were accumulated up to the last date of contact, usually the

termination date at the Wood River Refinery, or for transferred employees, the termination date at another Shell location.

We calculated approximate 95% confidence intervals (CI) of the SMRs assuming a Poisson distribution for the observed numbers of deaths. When the number of deaths was small, such as in the analysis of leukemia by cell type, we calculated exact 95% CI (12). Throughout this report, results are designated as statistically significant when the two-sided 95% CI of the SMR excludes the null value of 1.0. We used a computer program developed by Monson to calculate the SMRs (13). The most recent version of this program contains US mortality rates updated to 1980. The leukemia rates for 1975-1979 and 1980, however, were erroneously low because of the inadvertent exclusion of unspecified leukemias from the overall leukemia rates, starting in 1979 (R. Monson, personal communication). Therefore, we corrected the 1975-1979 leukemia rates as suggested by Monson (Memorandum to USDR users, 1-5-87) and replaced the 1980 rates with rates calculated from published US vital statistics for 1980 (14).

We used rates based on the Surveillance, Epidemiology and End Results (SEER) program to derive expected numbers of cell type-specific leukemia deaths occurring in or after 1970 (15). For leukemia deaths occurring before 1970, we used published 1968 US mortality data to calculate cell type-specific leukemia rates and to generate expected numbers (16). General population mortality rates for specific leukemia cell types were not available before 1968. It is likely that cell type-specific rates would

have increased during 1940 to 1970 as a result of more accurate diagnosis and reporting and, possibly, a true rise in incidence and mortality. If this were the case, the use of 1968 rates as referent rates for the period of 1940 through 1969 would overestimate the true expected numbers.

The SSA provided information on deaths occurring through 1984 and identified other employees as alive or lost to follow-up as of December 31, 1983. We included all deaths occurring in 1984 in the analyses; and, for the purpose of computing PY of observation, we assumed that men, identified as alive in 1983 and not reported as deceased in 1984, remained alive until December 31, 1984. This assumption could produce an underestimate of SMRs if there were underascertainment of deaths in 1984. However, the SMR for all causes for the overall study period of 1940 (or 1942) through 1984 was 0.81, whereas the SMR obtained when follow-up stopped at the end of 1983 was 0.77. This suggests that underascertainment did not occur.

We were not able to locate the death certificates of 151 (5%) of the reported decedents with at least six months of employment. In the analyses, we included these deaths in the SMRs for all causes. However, we did not adjust cause-specific observed numbers of deaths or the corresponding SMR to include a percentage of the deaths from unknown causes. Therefore, cause-specific SMRs are underestimated by an average of 5%.

RESULTS

Table 1 summarizes the vital status of the cohort as of January 1, 1985. Of the 9,484 white men, 6,266 (66%) were alive at the close of follow-up, 2,874 (30%) had died and 344 (4%) had unknown vital status. We located the death certificates of 2,733 (95%) of the white men who had died. Of the 1,024 white women, 728 (71%) were alive, and only 45 deaths had occurred. Follow-up was less complete for white women than for men: vital status was unknown for 25% of the women, and death certificates could not be located for 10 (22%) of the reported deaths. Of the 210 black men, 191 (91%) were alive, 6 (3%) had died and 13 (6%) were lost to follow-up. We located death certificates for the six decedents.

Table 2 provides information on the employment status and payroll classification of the cohort. Of the white men, 7,524 (79%) were ever hourly; 1,871 (20%) were always staff; 47 were staff, unknown if ever hourly; and 42 had unknown payroll classifications. Of the white men who were always staff, 1,109 (59%) had held PR jobs. Of the white women, only 167 (16%) were ever hourly, 852 were always staff and 781 (92%) of the women who were always staff had held NPR jobs. Of the black men, 89% were ever hourly.

Table 3 provides further information on employment characteristics and age distribution of the cohort. About 60% of the white men and 45% of the white women were hired before 1950, whereas all black men were hired after 1949. Sixty-eight per cent of the white men had worked for five or more years, and 27% had worked

for at least 25 years. In contrast, white women and black men tended to have worked for shorter durations, with 66% of the white women and 49% of the black men having fewer than 5 years of employment. White men and women had been followed for an average of about 28 and 21 years, respectively. Black men had a considerably shorter average period of observation (9.5 years).

Among white men, 43% of the total 261,737 PY were contributed at ages greater than 49 years. White women and black men were younger, with only 23% and 2%, respectively, of their PY contributed at ages above 49 years. Results of mortality analyses are presented below, separately for white men, white women and black men.

White men

Table 4 displays observed and expected numbers of deaths among white men. The total number of observed deaths was 2,874, whereas 3,568 deaths were expected. The corresponding SMR for all causes was 0.8, reflecting approximately a 20% deficit in overall mortality among these workers compared to US white men. Observed numbers of deaths from most specific disease categories were also appreciably fewer than expected, and most of these deficits were statistically significant. For all cancers combined, there were 661 observed and 728.6 expected deaths (SMR=0.9, 95% CI=0.8-1.0). If the 141 men for whom death certificates were not found were allocated to disease categories according to the cause distribution of the deaths from known causes, the cancer SMR would have been 1.0 (0.9-1.1).

There were similar mortality deficits among the 4,845 white men who had worked at the refinery for 10 or more years (table 5) and among the 6,999 men who had been followed for at least 20 years since starting work (table 6). In each of these two groups, there was a 30% excess of deaths from diseases of the blood and blood-forming organs, based on 8 observed and 6.2 expected deaths (men employed for 10 or more years) and on 9 observed and 6.9 expected deaths (men followed for at least 20 years since starting work). The following specific diagnoses were reported on the death certificates of the nine decedents with this underlying cause of death: aplastic anemia (N=3), secondary anemia (unspecified primary cause) (N=2), thrombocytopenic purpura (N=1), pernicious anemia (N=1), acute splenitis (N=1) and Felty's syndrome (N=1).

Table 7 contains a further description of mortality patterns for all causes and all cancer by duration of employment and time since starting work. The observed number of deaths from all causes was lower than the expected number by 14% to 25% in all duration of employment categories. The deficit was largest (44%) within 10 years of starting work but was still substantial (17%) among men who had been followed for 30-39 years since starting work.

Table 8 displays observed and expected numbers of deaths and SMRs for site-specific cancers. The observed number was approximately equal to or was less than the expected number for all sites except skin (observed/expected, 15/12.1), Hodgkin's disease (9/7.8), leukemia (44/28.2) and other lymphatic and hematopoietic

tissues (20/17.8). The SMR for leukemia was 1.6 (95% CI=1.1-2.1), reflecting a statistically significant 60% excess of deaths from this disease. For skin cancer, Hodgkin's disease and cancer of other lymphatic and hematopoietic tissues, the SMRs were only slightly elevated (SMRs: 1.2, 1.2 and 1.1, respectively), and none was statistically significant. There were statistically significant deficits of deaths from buccal cavity and pharynx cancer (6/22.5; SMR=0.3, 0.1-0.6) and from liver cancer (6/15.5; SMR=0.4, 0.1-0.8).

There were no marked differences between the sitespecific cancer SMRs for men who had worked at the refinery for at least 10 years (table 9) and the SMRs of the overall cohort. Among these men there were 33 observed and 18.9 expected leukemia deaths (SMR=1.7, 1.2-2.5).

As shown in table 10, men who were followed for at least 20 years since starting work had a leukemia SMR of 1.5 (1.0-2.1), based on 34 observed and 22.7 expected deaths. This was not materially different from the leukemia SMRs for the overall cohort and for men employed for at least 10 years at the refinery. These men also had slight excesses of cancers of the large intestine and rectum (85/78.4) and central nervous system (CNS) (17/15.0). The excesses of skin cancer (12/9.3), Hodgkin's disease (7/4.3) and cancer of other lymphatic and hematopoietic tissue (19/16.1) were slightly higher in this group of workers than in the overall cohort of white men.

The mortality patterns of ever hourly employees were generally similar to those of staff employees (tables 11 and 12).

However, the relative excess of leukemia was higher among staff (9/3.5; SMR=2.6, 1.2-4.9) than among hourly workers (35/24.5; SMR=1.4, 1.0-1.9) (table 12). A direct comparison of the leukemia mortality rates of staff employees with the rates of hourly employees yielded a rate ratio of 2.0, with a 95% CI of 0.9-4.1. All deaths from diseases of the blood and blood forming organs occurred among hourly employees, for whom there was a slight overall excess (9/8.2) (table 11).

Within the subcohort of always staff employees, there were no striking differences in mortality patterns between men in PR and NPR jobs (Appendix F, tables F1 and F2). The leukemia SMR was 2.1, based on 4 observed and 1.9 expected deaths, among men in PR jobs and 3.2, based on 5 observed and 1.6 expected deaths, among men in NPR jobs.

Table 13 further describes the leukemia mortality patterns of the overall cohort. The leukemia excess appeared to be largest in the 1950s (10/3.8, SMR=2.6), although excesses also occurred in the 1960s (11/6.8, SMR=1.6) and the 1970s (16/10.5, SMR=1.5). In the 1980s there was virtually no excess of leukemia (6/5.7, SMR=1.1). There was only one leukemia death in the 1940s, with an SMR of 0.8. The overall leukemia excess did not vary materially by period of hire, although the largest number of observed deaths and the only statistically significant excess occurred among men hired before 1940 (24/14.3; SMR=1.7, 1.1-2.5). This was due primarily to a 2.3-fold increase in leukemia among men hired in 1935-1939 (11/4.7). Among men hired before 1935, the leukemia SMR was 1.4 (13/9.6).

Although there was no clear pattern of increasing leukemia SMRs with increasing duration of employment, the SMR was somewhat larger among men who had worked at the refinery for at least 10 years (SMR=1.7, 1.2-2.5) than among men employed for fewer than 10 years (SMR=1.2, 0.6-2.1). There was no excess of leukemia within 10 years since first hire (1/2.0; SMR=0.5, 0.0-2.8). The largest excess occurred during the period of 10-39 years since starting work (SMR=1.9, 1.3-2.6) and persisted until at least 40 years since first hire had elapsed (SMR=1.1, 0.5-2.1).

Table 14 displays leukemia SMRs jointly by period of hire and period of death. Among men hired before 1940, there was a 2.5-fold increase in leukemia (17/6.8) during 1940-1969 and no excess thereafter (7/7.5). In contrast, among men hired in 1940 or later, no excess of leukemia was present before 1970 (5/5.2), whereas a 70% excess, based on 15 observed and 8.7 expected deaths, occurred after 1969.

Table 15 displays cell type-specific observed and expected numbers of leukemia deaths by period of death. Overall, the workers experienced a slight excess of myelocytic leukemia (15/12.4, SMR=1.2), a 2.1-fold increase in lymphocytic leukemia (16/7.6) and a 4.8-fold increase in monocytic leukemia (6/1.3). The excess of lymphocytic leukemia was highest in 1950-1959 (5/1.0; SMR=5.1), declined in 1960-1969 (6/2.1; SMR=2.8) and disappeared in 1970-1984 (5/4.5; SMR=1.1). There was no excess of myelocytic leukemia in 1950-1959 (0/1.8) or in 1960-1969 (2/3.0). In contrast, in 1970-1984, most of the overall leukemia excess was due to increased mortality from acute myelocytic

leukemia (12/5.0; SMR=2.4). There was an excess of monocytic leukemia from 1950 through 1979 (6/1.0; SMR=5.8), but no deaths from this cell type of leukemia occurred after 1979.

Analysis of cell type-specific leukemia by period of hire also revealed different patterns for lymphocytic and myelocytic leukemia. Men hired in or after 1940 had a 1.7-fold increase in deaths from myelocytic leukemia (11/6.4), whereas there was no excess of deaths from this cell type among men hired before 1940 (4/5.9). In contrast, the excesses of lymphocytic and monocytic leukemias were not related to period of hire (lymphocytic leukemia: hired before 1940, 9/4.3; hired in or after 1940, 7/3.2) (monocytic leukemia: hired before 1940, 4/0.6; hired in or after 1940, 2/0.6).

There were slight differences in the leukemia cell type distribution between ever hourly and always staff employees. Among the ever hourly, 13 (37%) of the leukemias were lymphocytic, 13 (37%) were myelocytic, 4 (11%) were monocytic and 5 (14%) were other or unspecified. Among the always staff, 3 (33%) were lymphocytic, 2 (22%) were myelocytic, 2 (22%) were monocytic and 2 (22%) were other or unspecified.

Six men with leukemia reported on the death certificate as a contributing, rather than underlying, cause of death were not included in any of the above analyses. Of these men, two had lymphocytic leukemia and were hired before 1940; one had acute myelocytic leukemia and was hired after 1940; one had unspecified leukemia and was hired before 1940; and two had unspecified leukemia and were hired after 1940. Appendix II provides further

details on employment and other characteristics of all subjects with leukemia mentioned on their death certificates.

Table 16 displays observed numbers of deaths and SMRs for diseases of the blood and blood forming organs among hourly workers. An excess occurred among men who were hired before 1940 (7/4.8; SMR=1.5, 0.6-3.0); among those who were employed for 20 or more years (7/4.0, SMR=1.7, 0.7-3.6); and among those who were followed for at least 30 years since starting work (8/4.4; SMR=1.8, 0.8-3.6).

White women

White women employed at the Wood River Refinery had lower mortality rates than US white women (table 17). The SMR for all causes was 0.6 (0.5-0.9), based on 45 observed and 71.2 expected deaths. There was a 20% excess of breast cancer (7/5.8; SMR=1.2, 0.5-2.5) and a two-fold increase in hematopoietic malignancies (4/2.0; SMR=2.0, 0.5-5.1) (table 18). The leukemia SMR was 1.2 (0.0-6.9), based on one observed and 0.8 expected deaths.

Black men

Black men employed at the refinery had lower mortality rates than US black men (table 19). The SMR for all causes was 0.7 (0.2-1.4), based on six observed and 9.3 expected deaths.

DISCUSSION

This study evaluated the mortality experience of 10,713 oil refinery workers. White men, who accounted for 88% of the overall cohort, had an average of nearly 28 years of follow-up during the 45-year study period of 1940-1985. Their mortality rates for all causes combined and for most major cause of death categories were much lower than those of white men in the general US population. The other noteworthy results of this study pertain to the statistically significant excess of leukemia among white men, present since 1950, and to the patterns of this excess by cell type, period of death and period of hire. These patterns include: (a) a marked shift from an excess of lymphocytic leukemia among deaths occurring before 1970 to an excess of acute myelocytic leukemia in 1970-1984, (b) the presence of lymphocytic and monocytic leukemia excesses among men hired both before 1940 and in or after 1940 and (c) restriction of the myelocytic leukemia excess to men hired in 1940 or later and dying in or after 1970.

The overall favorable mortality experience of the white men included in this study persisted among long-term employees, and it was still present after 40 years of follow-up. These results are consistent with most previous studies of oil refinery workers (3-10,17) and with the earlier investigation of Wood River Refinery employees (1). The strength and consistency of the findings suggest that the favorable mortality experience of oil refinery workers is real, rather than an artifact of incomplete follow-up (only 4% were lost to follow-up in the

present study). General factors which may be responsible for the apparent health advantage of oil refinery workers include selection of relatively healthy individuals for employment in the industry and maintenance of their healthier status through benefits deriving from the economic advantages of employment (18). Moreover, these findings point strongly to the absence of pervasive occupational hazards within the industry which might have a negative impact on employees' health.

We found a statistically significant 60% excess of leukemia deaths among white men at the refinery. This was smaller than the approximately two-fold increase reported in an earlier study of men at the same refinery (1). However, the present study was about 100% larger and included a longer period of observation than the previous study. The previous study also included a relatively large proportion of retirees. Although we did not examine the mortality experience of retirees per se, we did evaluate leukemia mortality by duration of employment. Among men employed for at least 20 years, a group which includes most retirees, the leukemia excess was also about 60%.

Several features of the association of leukemia with employment at the Wood River Refinery are important to consider further. First, there was no consistent increase in the leukemia SMR with duration of employment. The fact that there is little evidence of "dose-response" does not detract greatly from a causal interpretation of the observed association, however, because overall duration of employment may not be highly correlated with leukemogenic exposures, if any, at the refinery. The

pattern of leukemia mortality with time since first hire was more consistent with an excess attributable to occupational factors. There was no leukemia excess within the first 10 years of hire; variable excesses, ranging from 60 to 150%, but no consistent trend, occurred 10-39 years after hire; and there was, again, essentially no increased leukemia mortality 40 or more years after hire.

The leukemia excess was higher among staff than among hourly workers, who probably experienced the higher exposures to chemicals at the refinery, and there was little difference in the magnitude of the leukemia excess between men in PR and NPR jobs. These observations appear to be inconsistent with the hypothesis that the leukemia excess is the result of work-related exposures. However, classification of workers by payroll status and job categories may not have been adequate to distinguish their potential for leukemogenic exposures at the refinery. It is also possible that unidentified nonoccupational exposures or exposures at work sites other than the Wood River Refinery were responsible for the observed leukemia excess.

The relatively large number of leukemia deaths identified by this study (N=44 among white men) made it possible to evaluate the leukemia excess by cell type and by period of death. Of particular interest were the findings of a shift from an excess of lymphocytic leukemia among deaths occurring before 1970 to an excess of myelocytic leukemia in 1970 through 1984 and the presence of an excess of monocytic leukemia until the 1980s. The excess of myelocytic leukemia in 1970-1984 was due primarily to a

2.4-fold increase in acute myelocytic leukemia, as previously reported (1).

The difference in the cell type distribution between the two time periods could be accounted for in part, but not entirely, by the higher proportion of unspecified leukemias in 1950-1969 than in later years. In 1950-1969, there were three unspecified leukemias. If all of these were, and had been classified as myelocytic, the per cent myelocytic would have been 23%, and the myelocytic leukemia SMR would have been 1.0 (5 observed/4.8 expected). In contrast, 13 (59%) of the leukemias in 1970-1984 were myelocytic, and the SMR was 1.7. There were two unspecified leukemias during the latter time period. Diagnostic techniques for cell type-specific leukemia have improved during the past few decades, and misclassification between myelocytic and lymphocytic leukemias in 1950-1969 is another possible explanation for the change over time in the cell type distribution.

Benzene, which is present along with other aromatic hydrocarbons in oil refineries, is considered a cause of acute myelocytic leukemia (11) but not of leukemia of other cell types. Studies of rubber workers exposed to benzene, toluene and other organic solvents have suggested that these agents are associated with chronic lymphocytic leukemia (19,20). However, there is no firm evidence relating specific chemical agents to leukemia cell types other than that relating benzene to acute myelocytic leukemia.

Manufacturing processes at the Wood River Refinery have changed over time, leading to changes in the number of units

that produce or use benzene and in the percentage of benzene in refinery streams. The concentration of benzene in refinery streams was not more than 5% until 1941, when toluene units were built with one stream of 5% to 10% benzene. Benzene was also supplied by tank cars for the cumene plant (operating from 1943 to 1945) and the dodecyl benzene unit (1950-1954), and a coke oven product containing 65-88% benzene was delivered to the refinery from 1966 to early 1983. Benzene extraction units and catalytic reforming units, in operation since 1960, have benzene streams of 5% to 100%.

The increased amounts and concentrations of benzene present at the refinery were accompanied by enhanced efforts to control exposure. Thus, the percentage of benzene in refinery streams may not have been correlated directly with actual exposure. However, it is of interest that an excess of myelocytic leukemia was found only among workers hired in 1940 or later and that this excess was largely attributable to acute myelocytic leukemia.

The present study did not include an assessment of work-related exposures at the refinery. Therefore, it is not clear which specific exposure or exposures at the refinery were responsible for the overall leukemia excess or for the marked shift in the cell type distribution. The fact that an excess of lymphocytic leukemia was found among men hired before 1940 suggests that benzene was not entirely responsible for the overall excess of this cell type, since there was no corresponding increase in myelocytic leukemia among men hired before 1940.

Only three (3-5) of eight (3-10) studies of other groups of refinery workers, in addition to the earlier study of Wood River employees (1), have reported leukemia excesses. Morgan and Wong (5) found an SMR of 1.73 (1.09-2.60) in a study of about 6,000 refinery workers followed from 1945 to 1978, a result which is quite similar to the SMR of 1.6 in the present study. However, in the other two studies, the leukemia excesses were less than 20% and were not statistically significant. Divine (4) reported an SMR of 1.18 (0.87-1.56) in a cohort of almost 20,000 refinery and petrochemical workers followed from 1947 to 1977. Wen (3) found a leukemia SMR of 1.14 (0.81-1.57) among about 15,000 refinery workers followed from 1937 to 1978.

In the present study, there was no excess of certain cancers found to be increased in other groups of refinery workers, including cancer of the brain, lung, stomach, pancreas, bladder and kidney (21). However, there were excesses of skin cancer, Hodgkin's disease and other lymphatic and hematopoietic tissue cancer. For each of these, the excess was small and was not statistically significant. Moreover, there were no marked trends with period of hire, duration of employment or time since first hire. Studies of other groups of refinery workers have reported inconsistent results for each of these disease categories. For skin cancer, there have been three positive studies (3,5,6), with SMRs ranging from 1.22 to 2.16, and three negative studies (4,8,9), with SMRs ranging from 0.84 to 0.99. For Hodgkin's disease, two studies found slight excesses (3,4) (SMRs: 1.08 and 1.45, respectively), and four studies reported deficits

(3,6,9,10). For other lymphatic tissue cancers, two studies reported negative findings (7,8), and there were five positive studies with SMRs ranging from 1.15 to 1.58 (3-5,9,10). None of these SMRs was statistically significant.

This study found a slight excess of nonmalignant diseases of the blood among certain subgroups of white men. Only two studies of other groups of oil refinery workers have found an excess of these diseases. In the first study, the SMR was 2.2, based on 6 observed and 2.7 expected deaths (22). In the second, the SMR was 1.2, based on 9 observed and 7.5 expected deaths (8). The present study found no increased mortality from diseases of the blood in the overall cohort. However, there was a 30% excess among men employed for at least 10 years and among men followed for at least 20 years after hire. Of the nine men with diseases of the blood, three had aplastic anemia, which may be caused by exposure to benzene or by certain drugs. We have no information on the specific jobs or work-place exposures of these three men; therefore, can not determine whether their disease was occupationally related.

Like the white men included in this study, white women and black men employed at the refinery had favorable overall mortality experiences. However, because the numbers of women and black men were small, the study contained little information on their cause-specific mortality patterns. White women had no excess of leukemia (1 observed, 0.8 expected), and no leukemia deaths were reported among black men. However, black men tended to be

relatively young and recently hired, and their expected number for leukemia was only 0.06.

In summary, this study reinforces other available evidence that petroleum refinery workers have an overall mortality experience which is favorable relative to that of the general population. It also supports previous work which suggests that some, but not all, groups of oil refinery workers have an excess of leukemia. Assuming that the leukemia mortality patterns by cell type, period of hire and period of death seen in the present study are real and not due to misclassification by cell type, they have several implications:

(a) The restriction of the myelocytic leukemia excess to men hired in or after 1940 may be related to changes in exposures at the refinery in the 1940s or later. One possible explanation is an increased exposure to benzene resulting from the process changes which occurred at the refinery after 1940. However, this explanation is speculative because the changes may not have resulted in a concomitant increase in workers' benzene exposure levels and because other exposures, possibly relevant to leukemia, may have been introduced during this period. Also, the present study did not include a direct evaluation of the relation between leukemia and benzene or other chemical exposures, and an earlier case-control study of leukemia at the Wood River Refinery found no association with benzene (2).

(b) The excess of lymphocytic, but not myelocytic, leukemia among men hired before 1940 suggests that some exposure other than benzene was responsible.

(c) Finally, the lymphocytic leukemia excess among white men appeared to diminish in 1970-1984. It is possible that this trend is real and reflects a reduction in some unknown leukemogenic exposure related to this cell type. The acute myelocytic leukemia excess was also slightly lower in 1980-1984 (3/1.7, SMR=1.7) than in 1970-1979 (9/3.3; SMR=2.7), and there have been no deaths from monocytic leukemia in the 1980s. However, the expected numbers of cell type-specific leukemia deaths in 1980-1984 were rather small, and future observation of leukemia mortality will be necessary to evaluate the apparent reduction in the lymphocytic and monocytic leukemia excesses and to determine if the acute myelocytic leukemia excess will persist among Wood River Refinery employees.

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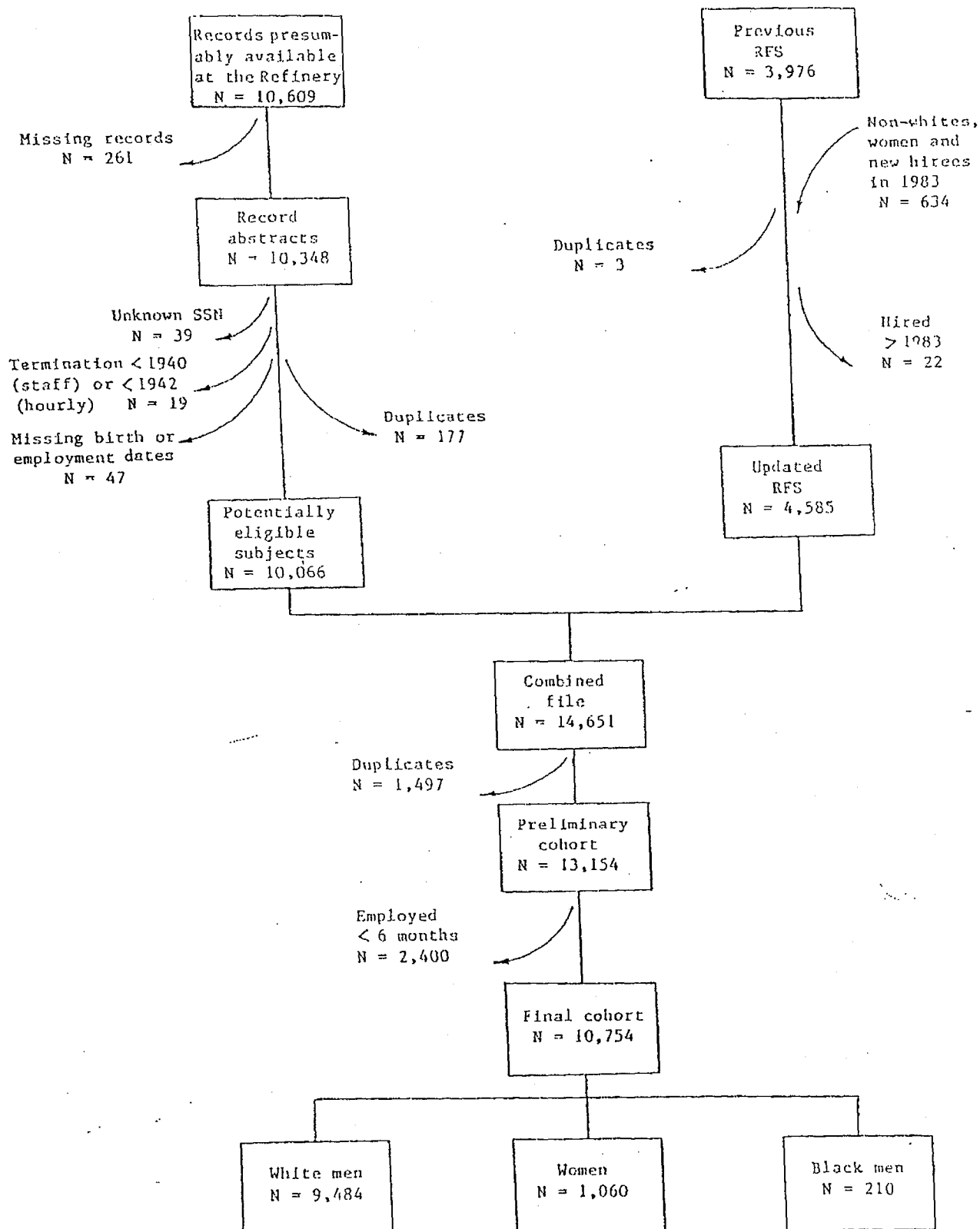


Figure. Data sources and cohort identification

Table 1

Distribution of Wood River Refinery
workers according to vital status

	White Men		White Women		Black Men	
	No.	%	No.	%	No.	%
Total:	9,484	100	1,024	100	210	100
Vital Status:						
Alive: *	6,266	66	728	71	191	91
Active	1,383	(22)	142	(20)	124	(65)
Not active	4,883	(78)	586	(81)	67	(35)
Deceased:	2,874	30	45	4	6	3
Death certificate obtained	2,733	(95)	35	(78)	6	(100)
Death certificate not obtained	141	(5)	10	(22)	0	(0)
Unknown:	344	4	251	25	13	6

* Employed at the Wood River Refinery as of 1-1-85.

Table 2

Distribution of Wood River Refinery workers
according to employment status and payroll classification

	White Men		White Women		Black Men	
	No.	%	No.	%	No.	%
Total:	9,484	100	1,024	100	210	100
Employment Status:						
Active	1,383	15	134	13	123	59
Pensioned	2,695	28	29	3	1	0
Terminated	4,389	46	844	82	84	40
Deceased*	323	3	4	0	0	0
Transferred	683	7	12	1	2	1
Unknown	11	0	1	0	0	0
Payroll Classification:						
Ever hourly:	7,524	79	167	16	186	89
Always hourly	6,416	(85)	154	(92)	180	(97)
Hourly and staff	1,101	(14)	10	(6)	6	(3)
Unknown if ever staff	7	(0)	3	(2)	0	(0)
Always staff:	1,871	20	852	83	22	(10)
PR†	1,109	(59)	71	(8)	9	(41)
NPR‡	754	(40)	781	(92)	13	(59)
Unknown if PR	8	(0)	0	(0)	0	(0)
Staff, unknown if ever hourly	47	1	2	0	0	0
Unknown if hourly or staff	42	0	3	0	2	1

* Died while actively employed.

† PR, ever employed in production-related jobs.

‡ NPR, employed only in nonproduction-related jobs.

Table 3

Distribution of Wood River Refinery workers
according to selected characteristics

	White men		White women		Black men	
	No	%	No	%	No	%
Total no. of workers:	9,484	100	1,024	100	210	100
Year of hire:						
<1940	2,515	27	28	3	0	0
1940-1949	3,219	34	435	42	0	0
≥1950	3,750	40	561	55	210	100
Duration of employment (yrs):						
0.5-4	3,043	32	680	66	102	49
5-14	2,483	26	270	26	97	46
15-24	1,425	15	40	4	11	5
≥25	2,533	27	34	3	0	0
PY* of follow-up:						
Total:	261,737	100	21,231	100	1,996	100
Average:	27.6	-	20.7	-	9.5	-
Age (yrs):						
<40	83,986	32	11,632	55	1,632	82
40-49	66,666	25	4,653	22	325	16
50-59	58,919	23	3,396	16	39	2
60-69	36,968	14	1,344	6	0	0
≥70	15,198	6	206	1	0	0

* PY, person-years

Table 4

Observed (obs) and expected (exp) numbers of deaths and SMRs for selected causes among white men employed at the Wood River Refinery

Cause of death	Obs	Exp	SMR	(95% CI [†])
All causes	2,874*	3,568.0	0.8	(0.8-0.8)
All cancers	661	728.6	0.9	(0.8-1.0)
Infective and parasitic diseases	14	59.9	0.2	(0.1-0.4)
Benign neoplasms	8	9.7	0.8	(0.4-1.6)
Diabetes mellitus	48	50.6	0.9	(0.7-1.3)
Diseases of the blood and blood forming organs	9	9.3	1.0	(0.4-1.8)
Diseases of the nervous system	14	31.7	0.4	(0.2-0.7)
Diseases of the circulatory system	1,441	1,850.3	0.8	(0.7-0.8)
Diseases of the respiratory system	136	224.5	0.6	(0.5-0.7)
Diseases of the digestive system	108	169.1	0.6	(0.5-0.8)
Diseases of the genito-urinary system	28	53.5	0.5	(0.4-0.8)
Senility and ill defined conditions	19	35.7	0.5	(0.3-0.8)
All external causes	228	301.5	0.8	(0.7-0.9)
Other known causes	17	32.8	0.5	(0.3-0.8)

* Includes 141 deaths for whom the death certificate and cause of death were not available.

[†] CI, confidence interval of the SMR.

Table 5

Observed and expected numbers of deaths and SMRs for
selected causes among white men who worked for 10 or more years
at the Wood River Refinery (N = 4,845)

Cause of death	Obs	Exp	SMR	(95% CI)
All causes	1,910*	2,459.2	0.8	(0.7-0.8)
All cancer	436	505.1	0.9	(0.8-1.0)
Infective and parasitic diseases	11	36.2	0.3	(0.2-0.5)
Benign neoplasms	6	6.3	1.0	(0.4-2.1)
Diabetes mellitus	34	35.5	1.0	(0.7-1.3)
Diseases of the blood and blood forming organs	8	6.2	1.3	(0.6-2.5)
Diseases of the nervous system	11	20.0	0.5	(0.3-1.0)
Diseases of the circulatory system	1,021	1,335.2	0.8	(0.7-0.8)
Diseases of the respiratory system	90	162.8	0.6	(0.4-0.7)
Diseases of the digestive system	67	110.2	0.6	(0.5-0.8)
Diseases of the genito- urinary system	21	37.5	0.6	(0.4-0.9)
Senility and ill-defined conditions	13	23.8	0.6	(0.3-0.9)
All external causes	112	153.1	0.7	(0.6-0.9)
Other known causes	8	21.2	0.4	(0.2-0.7)

* Includes 72 deaths for whom the death certificate and cause of death were not available.

Table 6

Observed and expected number of deaths and SMRs for selected causes among white men employed at the Wood River Refinery, 20 years after first hire (N=6,999)

Cause of death	Obs	Exp	SMR	(95% CI)
All causes	2,490*	2,930.0	0.8	(0.8-0.9)
All cancer	587	632.5	0.9	(0.9-1.0)
Infective and parasitic diseases	9	30.5	0.3	(0.1-0.6)
Benign neoplasms	7	7.2	1.0	(0.4-2.0)
Diabetes mellitus	45	42.5	1.1	(0.8-1.4)
Diseases of the blood and blood forming organs	9	6.9	1.3	(0.6-2.5)
Diseases of the nervous system	14	23.1	0.6	(0.3-1.0)
Diseases of the circulatory system	1,311	1,601.7	0.8	(0.8-0.9)
Diseases of the respiratory system	127	198.9	0.6	(0.5-0.8)
Diseases of the digestive system	96	129.0	0.7	(0.6-0.9)
Diseases of the genito-urinary system	27	39.2	0.7	(0.5-1.0)
Senility and ill defined conditions	17	29.6	0.6	(0.3-0.9)
All external causes	125	155.7	0.8	(0.7-1.0)
Other known causes	18	27.5	0.7	(0.4-1.0)

* Includes 102 deaths for whom the death certificate and cause of death were not available.

Table 7

Observed and expected numbers of deaths and SMRs for all causes and all cancer among white men employed at the Wood River Refinery by duration of employment and time since starting work

	All causes			All cancer		
	Obs	Exp	SMR	Obs	Exp	SMR
Duration of employment (yrs):						
0.5-4	612	711.9	0.9	146	143.9	1.0
5-14	580	687.8	0.8	134	136.9	1.0
15-24	744	931.6	0.8	151	178.4	0.8
>25	938	1,245.9	0.8	230	271.1	0.8
Years since starting work:						
<10	115	208.5	0.6	12	24.6	0.5
10-19	269	434.3	0.6	62	72.3	0.9
20-29	618	863.7	0.7	138	176.7	0.8
30-39	937	1,123.8	0.8	243	254.9	0.9
>40	935	946.9	1.0	206	201.8	1.0

Table 8

Observed and expected numbers of deaths and SMRs for
selected cancers among white men employed at the
Wood River Refinery

Cancer site	Obs	Exp	SMR	(95% CI)
All sites	661	728.6	0.9	(0.8-1.0)
Buccal cavity and pharynx	6	22.5	0.3	(0.1-0.6)
Esophagus	13	17.2	0.8	(0.4-1.3)
Stomach	27	38.6	0.7	(0.5-1.0)
Large intestine and rectum	66	67.1	1.0	(0.8-1.3)
Liver	6	15.5	0.4	(0.1-0.8)
Pancreas	31	39.4	0.8	(0.5-1.1)
Larynx	5	10.8	0.5	(0.2-1.1)
Lung	209	235.4	0.9	(0.8-1.0)
Skin	15	12.1	1.2	(0.7-2.0)
Bladder	17	22.5	0.8	(0.4-1.2)
Kidney	18	17.9	1.0	(0.6-1.6)
CNS	19	20.5	0.9	(0.6-1.5)
Lymphosarcoma	14	13.7	1.0	(0.6-1.7)
Hodgkin's disease	9	7.8	1.2	(0.5-2.2)
Leukemia	44	28.2	1.6	(1.1-2.1)
Other lymphatic and hematopoietic tissue *	20	17.8	1.1	(0.7-1.7)
Other and unknown	142	141.8	1.0	(0.8-1.2)

* Includes other lymphoma (ICD=202), multiple myeloma (ICD=203)
and polycythemia vera (ICD=208).

Table 9

Observed and expected numbers of deaths and SMRs
for selected cancers among white men who worked
for 10 or more years at the Wood River Refinery

Cancer site	Obs	Exp	SMR	(95% CI)
All sites	436	505.1	0.9	(0.8-1.0)
Buccal cavity and pharynx	4	15.4	0.3	(0.1-0.7)
Esophagus	7	12.0	0.6	(0.2-1.2)
Stomach	15	27.9	0.5	(0.3-0.9)
Large intestine and rectum	60	64.0	0.9	(0.7-1.2)
Liver	4	11.1	0.4	(0.1-0.9)
Pancreas	25	27.7	0.9	(0.6-1.3)
Larynx	2	7.6	0.3	(0.0-1.0)
Lung	130	160.9	0.8	(0.7-1.0)
Skin	9	7.6	1.2	(0.5-2.3)
Prostate	38	40.0	1.0	(0.7-1.3)
Bladder	12	16.8	0.7	(0.4-1.3)
Kidney	11	12.2	0.9	(0.5-1.6)
CNS	12	12.5	1.0	(0.5-1.7)
Lymphosarcoma	9	9.1	1.0	(0.5-1.9)
Hodgkin's disease	5	4.3	1.2	(0.4-2.7)
Leukemia	33	18.9	1.7	(1.2-2.4)
Other lymphatic and hematopoietic tissue	13	12.2	1.1	(0.6-1.8)
Other and unknown	47	44.1	1.1	(0.8-1.4)

Table 10

Observed and expected number of deaths and SMRs
for selected cancers among white men employed at the
Wood River Refinery, 20 years after first hire

Cancer site	Obs	Exp	SMR	(95% CI)
All sites	587	632.5	0.9	(0.9-1.0)
Buccal cavity and pharynx	5	19.2	0.3	(0.1-0.6)
Esophagus	13	15.2	0.9	(0.5-1.5)
Stomach	22	31.5	0.7	(0.4-1.1)
Large intestine and rectum	85	78.4	1.1	(0.9-1.3)
Liver	6	13.1	0.5	(0.2-1.0)
Pancreas	29	34.7	0.8	(0.6-1.2)
Larynx	4	9.5	0.4	(0.1-1.1)
Lung	193	211.6	0.9	(0.8-1.1)
Skin	12	9.3	1.3	(0.7-2.3)
Prostate	43	49.5	0.9	(0.6-1.2)
Bladder	16	20.5	0.8	(0.5-1.3)
Kidney	13	15.4	0.9	(0.5-1.5)
CNS	17	15.0	1.1	(0.7-1.8)
Lymphosarcoma	10	11.0	0.9	(0.4-1.7)
Hodgkin's disease	7	4.3	1.6	(0.7-3.3)
Leukemia	34	22.7	1.5	(1.0-2.1)
Other lymphatic and hematopoietic tissue	19	16.1	1.2	(0.7-1.9)
Other and unknown	59	55.8	1.1	(0.8-1.3)

Table 11

Observed and expected numbers of deaths and SMRs for selected causes
among white men employed at the Wood River Refinery according to payroll classification

	Ever hourly				Always Staff			
	Obs	Exp	SMR	(95% CI)	Obs	Exp	SMR	(95% CI)
All causes	2,589	3,126.8	0.8	(0.8-0.9)	263	420.2	0.6	(0.6-0.7)
All cancer	585	636.3	0.9	(0.8-1.0)	68	87.6	0.8	(0.6-1.0)
Infective and parasitic Diseases	12	53.1	0.2	(0.1-0.4)	2	6.5	0.3	(0.0-1.1)
Benign neoplasms	7	8.4	0.8	(0.3-1.7)	1	1.2	0.8	(0.0-4.5)
Diabetes mellitus	44	44.5	1.0	(0.7-1.3)	4	5.8	0.7	(0.2-1.8)
Diseases of the blood and blood forming organs	9	8.2	1.1	(0.5-2.1)	0	1.0	0.0	(0.0-3.5)
Diseases of the nervous system	13	27.3	0.5	(0.3-0.8)	1	4.2	0.2	(0.0-1.3)
Diseases of the circulatory system	1,316	1,638.8	0.8	(0.8-0.9)	117	201.8	0.6	(0.5-0.7)
Diseases of the respiratory system	129	199.1	0.6	(0.5-0.8)	6	24.2	0.2	(0.1-0.5)
Diseases of the digestive system	93	146.1	0.6	(0.5-0.8)	15	21.9	0.7	(0.4-1.1)
Diseases of the genito-urinary system	25	47.7	0.5	(0.3-0.8)	3	5.5	0.5	(0.1-1.6)
Senility and ill defined conditions	19	30.8	0.6	(0.4-1.0)	0	4.7	0.0	(0.0-0.8)
All external causes	199	249.0	0.8	(0.7-0.9)	26	49.8	0.5	(0.3-0.8)
Other known causes	14	27.9	0.5	(0.3-0.8)	3	4.7	0.6	(0.1-1.9)

Table 12

Observed and expected numbers of deaths and SMRs for selected cancers
among white men employed at the Wood River Refinery according to payroll classification

Cancer site	Ever hourly				Always Staff			
	Obs	Exp	SMR	(95% CI)	Obs	Exp	SMR	(95% CI)
All sites	585	636.5	0.9	(0.8-1.0)	68	87.6	0.8	(0.6-1.0)
Buccal cavity and pharynx	5	19.6	0.3	(0.1-0.6)	1	2.7	0.4	(0.0-2.0)
Esophagus	13	15.0	0.9	(0.5-1.5)	0	2.1	0.0	(0.0-1.8)
Stomach	22	34.4	0.6	(0.4-1.0)	4	4.0	1.0	(0.3-2.5)
Large intestine and rectum	84	79.1	1.1	(0.9-1.3)	8	10.1	0.8	(0.3-1.6)
Liver	6	13.7	0.4	(0.2-1.0)	0	1.7	0.0	(0.0-2.2)
Pancreas	26	34.6	0.8	(0.5-1.1)	4	4.6	0.9	(0.2-2.2)
Larynx	5	9.5	0.5	(0.2-1.2)	0	1.3	0.0	(0.0-2.9)
Lung	188	204.1	0.9	(0.8-1.1)	19	29.7	0.6	(0.4-1.0)
Skin	13	10.3	1.3	(0.7-2.2)	2	1.8	1.1	(0.1-4.1)
Prostate	41	46.4	0.9	(0.6-1.2)	3	4.9	0.6	(0.1-1.8)
Bladder	17	20.1	0.8	(0.5-1.4)	0	2.3	0.0	(0.0-1.6)
Kidney	16	15.6	1.0	(0.6-1.7)	2	2.2	0.9	(0.1-3.2)
CNS*	14	17.4	0.8	(0.4-1.4)	4	3.0	1.4	(0.4-3.5)
Lymphosarcoma	13	11.9	1.1	(0.6-1.9)	1	1.8	0.6	(0.0-3.2)
Hodgkin's disease	8	6.5	1.2	(0.5-2.4)	1	1.2	0.9	(0.0-4.8)
Leukemia	35	24.5	1.4	(1.0-1.9)	9	3.5	2.6	(1.2-4.9)
Other lymphatic and hematopoietic tissue	19	15.4	1.2	(0.7-1.9)	1	2.3	0.4	(0.0-2.4)
Other and unknown	60	58.6	1.0	(0.8-1.3)	7	8.6	0.8	(0.3-1.7)

* CNS. central nervous system.

Table 13

Observed numbers of leukemia deaths and SMRs
among white men employed at the Wood River Refinery,
according to selected characteristics

	Obs	SMR	95% CI
Period of death:			
1940-1949	1	0.8	0.0-4.3
1950-1959	10	2.6	1.3-4.9
1960-1969	11	1.6	0.8-2.9
1970-1979	16	1.5	0.9-2.5
>1980	6	1.1	0.4-2.3
Period of hire:			
<1940	24	1.7	1.1-2.5
1940-1949	15	1.4	0.8-2.3
>1950	5	1.6	0.5-3.8
Duration of employment (yrs):			
0.5-9	11	1.2	0.6-2.1
10-19	10	1.8	0.9-3.4
>20	23	1.7	1.1-2.5
Years since starting work:			
<10	1	0.5	0.0-2.8
10-19	9	2.5	1.2-4.8
20-29	10	1.6	0.7-2.9
30-39	16	1.8	1.1-3.0
>40	8	1.1	0.5-2.1

Table 14

Observed numbers of leukemia deaths and SMRs
among white men employed at the Wood River Refinery,
according to period of hire and period of death

Period of hire	Period of death				Total	
	1940-1969		1970-1984			
	Obs	SMR	Obs	SMR	Obs	SMR
<1940	17	2.5	7	0.9	24	1.7
≥1940	5	1.0	15	1.7	20	1.4
Total:	22	1.8	22	1.4	44	1.6

Table 15

Observed and expected numbers of leukemia
deaths by cell type and decade of death among
white male employees of the Wood River Refinery

Decade of death	Cell type	Obs [*]	Exp [†]	SMR
1950-1959	All lymphocytic	5	1.0	5.1
	All myelocytic	0	1.8	0.0
	Monocytic	1	0.23	4.4
	Other and unspecified	4	0.75	5.3
1960-1969	All lymphocytic	6	2.1	2.8
	All myelocytic	2	3.0	0.7
	Monocytic	3	0.41	7.3
	Other and unspecified	0	1.4	0.0
1970-1984	Lymphocytic	5	4.5	1.1
	Acute	1	0.70	1.4
	Chronic	4	3.1	1.3
	Other	0	0.69	0.0
	Myelocytic	13	7.6	1.7
	Acute	12	5.0	2.4
	Chronic	1	2.1	0.5
	Other	0	0.44	0.0
	Monocytic	2	0.63	3.2
	Other and unspecified	2	3.3	0.6

*. One death which occurred in 1947 is not included.

† The expected numbers are based on US Vital Statistics, 1968 (16), for deaths that occurred in the 1950's and 1960's and on SEER data (15) for deaths that occurred in 1970-1984.

Table 16

Observed numbers of deaths and SMRs for diseases
of the blood and blood forming organs among white male
hourly employees at the Wood River Refinery,
according to selected characteristics

	Obs	SMR	(95% CI)
Period of hire:			
<1940	7	1.5	(0.6-3.0)
1940-1949	2	0.7	(0.8-2.4)
<u>>1950</u>	0	0.0	(0.0-10)
Duration of employment:			
0.5-9	1	0.4	(0.0-2.2)
10-19	1	0.6	(0.0-3.3)
<u>>20</u>	7	1.7	(0.7-3.6)
Years since starting work:			
<20	0	0.0	(0.0-2.3)
20-29	1	0.6	(0.0-3.1)
<u>>30</u>	8	1.8	(0.8-3.6)

Table 17

Observed and expected number of deaths and SMRs for
selected causes among 1,024 white women employed at the
Wood River Refinery

	Obs	Exp	SMR	(95% CI)
All causes *	45	71.2	0.6	(0.5-0.9)
All cancers	19	23.7	0.8	(0.5-1.3)
Diseases of nervous systems	1	1.2	0.9	(0.0-4.8)
Diseases of circulatory system	5	23.8	0.2	(0.1-0.5)
Respiratory diseases	1	3.3	0.3	(0.0-1.7)
Diseases of digestive system	1	4.1	0.3	(0.0-1.4)
Diseases of genito- urinary system	1	1.3	0.8	(0.0-4.4)
Senility and ill-defined conditions	1	0.8	1.3	(0.0-7.1)
All external causes	3	6.7	0.5	(0.1-1.3)
Other known causes	2	1.2	1.7	(0.2-6.1)

* Includes 10 deaths for whom the death certificate and cause of death were not available.

Table 18

Observed and expected number of deaths and SMRs for
selected cancers among 1,024 white women employed at the
Wood River Refinery

Cancer site	Obs	Exp	SMR	(95% CI)
All cancer	19	23.7	0.8	(0.5-1.3)
Digestive system	0	4.8	0.0	(0.0-0.8)
Lung	2	3.1	0.6	(0.1-2.3)
Breast	7	5.8	1.2	(0.5-2.5)
Lymphosarcoma	0	0.4	0.0	(0.0-8.9)
Hodgkin's disease	1	0.3	3.6	(0.1-20)
Leukemia	1	0.8	1.2	(0.0-6.9)
Other lymphatic and hematopoietic tissue	2	0.5	3.8	(0.4-14)
Other and unknown sites	6	8.0	0.8	(0.3-1.6)

Table 19

Observed and expected number of deaths and SMRs for selected causes among 210 black men employed at the Wood River Refinery

Cause of death	Obs	Exp	SMR	(95% CI)
All causes	6	9.3	0.7	(0.2-1.4)
All cancers	0	0.8	0.0	(0.0-4.7)
Infective and parasitic diseases	1	0.1	7.2	(0.1-40)
Diseases of circulatory system	1	1.8	0.6	(0.0-3.2)
All external causes	4	4.3	0.9	(0.3-2.4)

APPENDIX A

Classification of Production-related (PR)
and Nonproduction-related (NPR) Jobs

Classification of production-related (PR)
and nonproduction-related (NPR) jobs

<u>Job Title</u>	<u>Production-related*</u>
Accountant	N
Accounting Assistant	N
Administrative Supt.	N
Adv. Products Mgr.	N
Alkylation Mgr.	Y
Analyst	N
Assistant	N
Asst. Mgr. 'Comp.	Y
Buyer	N
Carpenter and Rigging	Y
Cat Cracking Ass't. Mgr.	Y
Chemist	Y
Chemist Co-Op Student	Y
Clerk	N
Clerk Summers	N
Clerk-Shipping	N
Console Operator	N
Craft Foreman	Y
Data Proc. Assistant	N
Data Proc. Chief	N
Designer Draftsman	N
Draftsman	N
Duplicating Operator	N
Editor	N
Employee Relations Represen.	N
Employee Supervisor	N ?
Eng. Office Mgr.	N
Eng. Office Ass't. Mgr.	N
Engineer	N
Engineer Co-Op Student	N

<u>Job Title</u>	<u>Production-related*</u>
Engineer Field Ass't. Mgr.	Y
Engineer Foreman	Y
Engineer Service Mgr.	N
Engineer Student Trainee	N
Engineer Supervisor	N
Envir. Conservation Mgr.	N
Estimator	N
File and Mail Clerk	N
File Clerk	N
Foreman and Safety Inspector	Y
Foreman Supervisor	Y
Fuels Mgr.	N
Gas Asst. Mgr.	Y
Gate Captain	N
Gateman	N
Glass Blower	Y
Group Leader	N
Ind. Rel. Asst. Mgr.	N
Info. Services Assistant.	N
Inspector	Y
Inspector Inst.	Y
Key punch Operator	N
Lab A-Co-Op Student	Y
Lab Technician	Y
Lab Assistant	Y
Lab Technician	Y
Lab Technician - Ref. Lab	Y
Laboratory Assistant	Y
Laborer	Y
Laborer Operator	Y
Mail Carrier	N
Manager Compounding	Y
Manager Construction	N
Manager Employee Relations	N
Manager Treas.	N

<u>Job Title</u>	<u>Production-related*</u>
Manager Utilities	N
Material Analyst	N
Medical Director	N
Mgr. Aromatics	Y
Mgr. Cat. Crkg.	Y
Mgr. Compounding	Y
Mgr. Construction	N
Mgr. Econ. & Schedule	N
Mgr. Emp. Relations	N
Mgr. Eng. Office	N
Mgr. Fuels	N
Mgr. Ind. Rel. Ass't.	N
Mgr. Indl. Prod.	N
Mgr. Lube Oils Ass't.	N
Mgr. Pipefitter & I R	N
Mgr. Product Planning	N
Mgr. Purchasing Ass't.	N
Mgr. Refinery Lab	N
Mgr. Safety	N
Nurse	N
Office Assistant	N
Office Emp. Head	N
Office Secretary	N
Office Supervisor	N
Oil Accounting Supervisor	N
Oil Mvmt. Supervisor	N
Operations Foreman	Y
Operations Supervisor	Y
Operator Assistant	Y
Operator Foreman	Y
Operator Machine	Y
Operator Manager	Y
Operator Superintendent	N
Operator Supervisor	Y
Operator Telephone	N

<u>Job Title</u>	<u>Production-related*</u>
Opr. Duplicating	N
Ops. Supervisor	Y
Patrolman	N
Personnel Asst. Mgr.	N
Pipefitter	Y
Pipefitter Foreman	Y
Planning Coordinator	N
Process Superintendent	N
Process Manager	Y
Process Superintendent	N
Programmer	N
Purchasing Assistant	N
Purchasing Mgr.	N
Ref. Auditor	N
Refinery Lab Mgr.	N
Refinery Mgr.	N
Refinery Superintendent	N
Refinery Supervisor	N
Refinery Superintendent	N ?
Res. Technician	Y
Research Chemist	Y
Research Director	N
Research Engineer	Y
Research Lab	Y
Research Physicist, Asst. Chief	Y
Research Services Mgr.	N
Research Technician	Y
Safety Inspector	Y
Safety Mgr.	N
Safety Supervisor	N
Sched. Assistant	N
Secretary	N
Security Supervisor	N
Shift Foreman	Y
Steno-Clerk	N

<u>Job Title</u>	<u>Production-related*</u>
Steno-Secretary	N
Stenographer	N
Stores Mgr.	N
Supervisor	?
Supervisor Material	N
Supervisor Plant Protection	N
Technician	N
Technician Advisor	N
Technician Assoc.	N
Technician Mgr.	N
Technologist	N
Tool Expeditor	N
Training Rep.	N
Treasury Mgr.	N
Treasury Supervisor	N
Typist	N
Utilities Ass't. Mgr.	N
Yardman	Y

* A production-related job was one that involved routine or regular (at least 20% of the time) potential exposure to chemical substances in the refinery. For job titles with questionable exposure, decision was made on the basis of the department in which the worker was employed.

APPENDIX B
Record Abstract Form

WOOD RIVER
RECORD ABSTRACT

Date _____

Init. _____

Box No. _____

1. Type of record _____ 1
2. Name (last, first, MI) _____ 31
3. Social security number _____ 32 _____ 40
4. Wood River number _____ 41 _____ 45
5. Sex (M=1, F=2, U=9) _____ 47
6. Race (W=1, B=2, Oth=3, U=9) _____ 48
7. Date of BIRTH (U=9) _____ 49 _____ 54
8. Date of FIRST EMPLOYMENT (U=9) _____ 55 _____ 60
9. EQUATED EMPLOYMENT date (U=9) _____ 61 _____ 65
10. Date of most recent TERMINATION (U=9) _____ 67 _____ 72
11. Employment status _____
(term=1, ret=2, laid-off=3, deceased=4, transf=8, U=9) 73
12. Last payroll classification _____
(Hourly=1, Staff=2, U=9) 74
13. Ever hourly (Y=1, N=0, U=9) _____ 75
14. Last date HOURLY (Never hourly=8, U=9) _____ 76 _____ 81
15. Type of staff position _____
(Exp=1, Not exp=0, U=9, Never staff=8) 82
16. Date of DEATH _____
(None=0, U=9) 83 _____ 88
17. State of death _____ 89 _____ 90
18. Marital status _____
(M=1, S=2, W=3, D=4, U=9) 91

19. Name of most recent spouse _____

20. Last address _____

21. Last telephone number _____

22. Other tracing information (veteran status, new employment, physician, etc.) _____

APPENDIX C

Documentation of Merging Procedures
Used to Combine Computer Files

Merging of Abstract and Previous RFS* Records

<u>Variable</u>	<u>Source of the merged record</u>
Record type	Abstract
Name	Abstract
Wood River No.	Previous RFS
Sex	Previous RFS
Race	Previous RFS
Birth date	Previous RFS
Hire date	Abstract
Equated employment date	Abstract
Termination date	Previous RFS
Employment status	"Termination reason" in Previous RFS
Last payroll classification	Abstract
Last date hourly	Abstract
Type of staff position	Abstract
Date of death	Previous RFS

* Previous RFS, previous retrospective follow-up study of
the Wood River Refinery workers (1).

APPENDIX D
Vital Status Ascertainment

VITAL STATUS FOLLOW-UP

Social Security Administration Vital Status Follow-up

The SSA has a Summary Earnings Record (SER) on file for each individual to whom a SSN has been issued since 1936. The SER contains annual taxable earnings as well as demographic data. It is to this and other SSA record systems that death information is posted when it is reported to SSA. Reporting is motivated by the existence of survivors' benefits and lump sum death payments. It has been estimated that reporting of deaths to the SER is about 91% complete.

Since 1962, the SSA has also maintained the Master Beneficiary Records file (MBR). The MBR contains a record for each person entitled to receive retirement, survivors or disability insurance. Mortality coverage is higher on the MBR than on the SER. It is estimated that less than 2% of decedents who had received benefits during their life had no death indication on the MBR.

The numident file is a numerical file by SSN of the information contained on the SSA application form plus claim-related information. Information on the SSA application form includes name, SSN, birth date, mother's maiden name and father's surname.

deceased, the NDI provides the name of the state in which the death occurred, the date of death and the corresponding death certificate number. A copy of the death certificate can then be purchased directly from the state office.

The matching of study records with the NDI uses the following information: an individual's first name, middle initial, last name, father's surname (for married women), SSN, birth date, sex and race. The criteria for matching include at least one of the following seven combinations of data items:

1. SSN and first name
2. SSN and last name
3. SSN and father's surname
4. If the subject is a woman: SSN, last name
(submitted) and father's surname (NDI record)
5. Month and exact year of birth, first and last name
6. Month and exact year of birth, first name, father's
surname
7. If the subject is a woman: month and exact year of
birth, first name, last name (submitted) and
father's surname (NDI record)
8. Month and exact year of birth, first and middle
initials, last name.
9. Month and $\pm$ 1 year of birth, first and middle
initials, last name

By submitting the SSN and the first six letters of the surname to the Records Use and Services Branch of the SSA, it is possible to identify an individual as belonging to one of the following categories:

1. Death - State where death claim was filed
2. Death - State of last residence
3. Death - Funeral Director's notice
4. Assumed living
5. Status unknown
6. SSN Unmatched
7. Invalid SSN

First, the computerized search is done on the numident file to identify cases belonging to the "Death - State where death claim was filed" and the "Unmatched" categories. Then it continues with the MBR search identifying cases belonging in the "Death - State of Last Residence" and some of the "Assumed Living". The last step is the SER search to identify cases belonging in the "Death - Funeral Director's Notice", "Assumed Living", "Status Unknown", and "Invalid SSN's".

The National Death Index (NDI)

The NDI is a computerized index to the death certificates filed in each state vital records office and is capable of identifying each person dying in the United States, starting in 1979, using a standard set of information. When a name submitted is identified by the NDI to be

10. Month and ± 1 year of birth, first and last name
11. Month and day of birth, first and last name
12. Month and day of birth, first and middle initials,
last name.

Upon receiving the NDI search results, an individual judgment is then made on each possible record match to verify a true match. The results of the NDI search for the present study are summarized in the Figure.

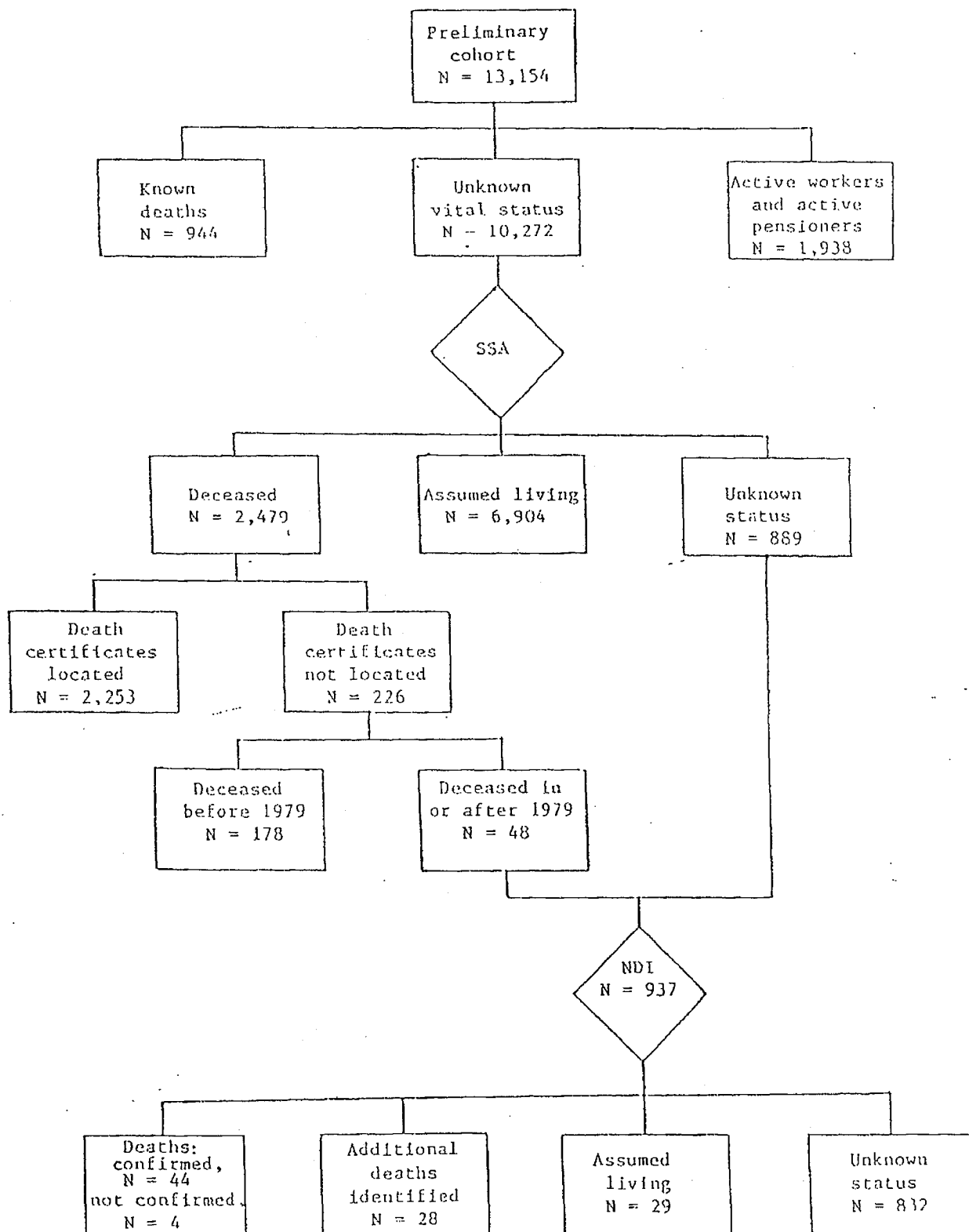


Figure Vital status ascertainment

APPENDIX E
Nosologic Coding for Leukemia

Appendix F

Nosologic Coding of Leukemia

Nosologic coding of causes of death used in this study was based on the Eighth Revision of the International Classification of Diseases, (ICD) (25) which was adopted in 1968. In the Sixth Revision of the ICD, the four-digit codes allowed for a distinction to be made between lymphatic and myeloid leukemia and between acute and chronic forms of the disease. In the Seventh Revision, all acute leukemias were grouped together, and it was thus impossible to distinguish among acute leukemia cell types (table E1).

According to the Eighth Revision, however, lymphocytic, myelocytic and monocytic leukemias are three separate categories based on three-digit codes and each category is subdivided into acute, chronic and unspecified (table E2). This is basically the same classification system used in the Ninth Revision, except for the code for other and unspecified cell types of leukemia. In the Ninth Revision, code 208 (leukemia of unspecified cell type) includes leukemia, not otherwise specified (NOS), acute leukemia NOS, chronic leukemia NOS, stem cell leukemia, and blast cell leukemia. In the Eighth Revision, these leukemia cell types were included under code 207 together with subleukemic, myeloproliferative, and megakaryocytic leukemia, etc.

Table E1

Classification Of Selected Leukemia Cell Types In The 6th-9TH
Revisions Of The International Classification of Diseases (23-26)

Leukemia cell type	ICD Codes			
	6th Revision (1948-1958)	7th Revision (1959-1967)	8th Revision (1968-1978)	9th Revision (1979-Present)
Lymphatic	204.0			
-acute			204.0	204.0
-chronic		204.0	204.1	204.1
-unspecified		204.0	204.9	204.9
Myeloid	204.1			
-acute			205.0	205.0
-chronic		204.1	205.1	205.1
-unspecified		204.1	205.9	205.9
Monocytic	204.2	204.2		
-acute			206.0	206.0
-chronic			206.1	206.1
-unspecified			206.9	206.9
Acute leukemia, unspecified cell type	204.3			
All acute leukemia		204.3		
Other and unspecified leukemia	204.4	204.9	207	
Other specified leukemia				207
Leukemia of unspecified cell type				208

Table E2

Classification Of Leukemia In The 8th Revision, ICDA (25)

Code	204	LYMPHATIC LEUKEMIA
		Includes: aleukemia, leukemia
		(aleukemic):
		lymphatic, lymphoblastic,
		lymphogenous, lymphoid,
		splenolymphatic
	204.0	Acute
	204.1	Chronic
	204.9	Unspecified
Code	205	MYELOID LEUKEMIA
		Includes: aleukemia, leukemia
		(aleukemic):
		granulocytic, myeloblastic,
		myelocytic, myelogenous,
		myelosclerotic, myelosis (aleukemic),
		monomyelocytic, eosinophilic,
		basophilic, mixed cell,
		splenomyelogenous
	205.0	Acute
	205.1	Chronic
	205.9	Unspecified

Code	206	MONOCYTIC LEUKEMIA
		Includes: aleukemia, leukemia
		(aleukemic):
		histiocytic, monoblastic,
		monocytic, reticular cell
	206.0	Acute
	206.1	Chronic
	206.9	Unspecified

Code	207	OTHER AND UNSPECIFIED LEUKEMIA
		Includes: aleukemia, leukemia
		(aleukemic): NOS, giant cell,
		megakaryocytic, stem cell,
		plasma cell, plasmacytic,
		blast cell, hemoblastic, mast
		cell, Rieder cell
	207.0	Leukemia, acute
	207.1	Leukemia, chronic
	207.2	Acute erythremia
	207.9	Leukemia (unspecified),
		subleukemic,
		myeloproliferative,
		eosinophilic

APPENDIX F

Mortality Patterns Among Always Staff
Employees in PR and NPR Jobs

Table F1

Observed and expected numbers of deaths and SMRs for selected causes
among white men employed at the Wood River Refinery
according to payroll classification

	Ever hourly				Always Staff							
	Obs	Exp	SMR	(95% CI)	Production related				Non-production related			
	Obs	Exp	SMR	(95% CI)	Obs	Exp	SMR	(95% CI)	Obs	Exp	SMR	(95% CI)
All causes	2,588	3,126.4	0.8	(0.8-0.9)	127	228.7	0.6	(0.5-0.7)	136	190.0	0.7	(0.6-0.9)
All cancer	583	636.3	0.9	(0.8-1.0)	32	48.3	0.7	(0.5-0.9)	37	38.9	1.0	(0.7-1.3)
Infective and parasitic Diseases	12	53.1	0.2	(0.1-0.4)	1	3.5	0.3	(0.0-1.6)	1	3.0	0.3	(0.0-1.8)
Benign neoplasms	7	8.4	0.8	(0.3-1.7)	1	0.7	1.4	(0.0-8.0)	0	0.5	0.0	(0.0-6.8)
Diabetes mellitus	44	44.5	1.0	(0.7-1.3)	2	3.2	0.6	(0.1-2.3)	2	2.7	0.8	(0.1-2.7)
Diseases of the blood and blood forming organs	9	8.2	1.1	(0.5-2.1)	0	0.6	0.0	(0.0-6.6)	0	0.5	0.0	(0.0-7.6)
Diseases of the nervous system	13	27.3	0.5	(0.3-0.8)	1	2.4	0.4	(0.0-2.4)	0	1.8	0.0	(0.0-2.0)
Diseases of the circulatory system	1,316	1,638.5	0.8	(0.8-0.9)	50	106.7	0.5	(0.4-0.6)	67	94.4	0.7	(0.6-0.9)
Diseases of the respiratory system	129	199.1	0.7	(0.5-0.8)	2	12.7	0.2	(0.0-0.6)	4	11.5	0.4	(0.1-0.9)
Diseases of the digestive system	93	146.1	0.6	(0.5-0.8)	7	12.3	0.6	(0.2-1.2)	8	9.5	0.9	(0.4-1.7)
Diseases of the genito-urinary system	25	47.7	0.5	(0.3-0.8)	0	2.8	0.0	(0.0-1.3)	3	2.7	1.1	(0.2-3.3)
Senility and ill defined conditions	19	30.8	0.6	(0.4-1.0)	0	2.7	0.0	(0.0-1.4)	0	2.0	0.0	(0.0-1.8)
All external causes	199	249.0	0.8	(0.7-0.9)	18	29.6	0.6	(0.4-1.0)	7	20.0	0.4	(0.1-0.7)

Table F2
Observed and expected numbers of deaths and SMRs for selected cancers among
white men employed at the Wood River Refinery according to job classification

Cancer Site	Ever hourly				Always staff							
	Obs.	Exp	SMR	(95% CI)	Production related				Non-production related			
					Obs	Exp	SMR	(95% CI)	Obs	Exp	SMR	(95% CI)
All cancer	584	636.5	0.9	(0.8-1.0)	32	48.3	0.7	(0.5-0.9)	37	38.9	1.0	(0.7-1.3)
Buccal cavity and pharynx	5	19.6	0.3	(0.1-0.6)	0	1.5	0.0	(0.0-2.4)	1	1.2	0.8	(0.0-4.6)
Digestive system	157	181.4	0.9	(0.7-1.0)	8	12.4	0.6	(0.3-1.3)	9	10.6	0.9	(0.4-1.6)
Esophagus	13	15.0	0.9	(0.5-1.5)	0	1.1	0.0	(0.0-3.2)	0	0.9	0.0	(0.0-4.1)
Stomach	22	34.4	0.6	(0.4-1.0)	2	2.1	1.0	(0.1-3.4)	2	1.9	1.1	(0.1-3.8)
Large intestine and rectum	84	79.1	1.1	(0.9-1.3)	3	5.4	0.6	(0.1-1.4)	5	4.6	1.1	(0.3-2.3)
Liver	6	13.7	0.4	(0.2-1.0)	0	0.9	0.0	(0.0-4.1)	0	0.8	0.0	(0.0-4.7)
Pancreas	26	34.5	0.8	(0.5-1.1)	3	2.5	1.2	(0.3-3.5)	1	2.1	0.5	(0.0-2.7)
Larynx	5	9.5	0.5	(0.2-1.2)	0	0.7	0.0	(0.0-5.2)	0	0.6	0.0	(6.0-6.5)
Lung	188	204.1	0.9	(0.8-1.1)	6	16.7	0.4	(0.1-0.8)	13	12.9	1.0	(0.5-1.7)
Skin	13	10.3	1.3	(0.7-2.2)	2	1.0	2.0	(0.2-7.1)	0	0.7	0.0	(0.0-5.0)
Prostate	41	46.4	0.9	(0.6-1.2)	1	2.4	0.4	(0.0-2.3)	2	2.5	0.8	(0.1-2.9)
Bladder	17	20.1	0.9	(0.5-1.4)	0	1.2	0.0	(0.0-3.2)	0	1.1	0.0	(0.0-3.3)
Kidney	16	15.6	1.0	(0.6-1.7)	1	1.3	0.8	(0.0-4.4)	1	1.0	1.0	(0.0-5.7)
(CNS*)	14	17.4	0.8	(0.4-1.4)	2	1.7	1.2	(0.1-4.2)	2	1.2	1.6	(0.2-5.9)
Lymphosarcoma	13	11.9	1.1	(0.6-1.9)	0	1.0	0.0	(0.0-3.7)	1	0.8	1.3	(0.0-7.3)
Hodgkin's disease	8	6.5	1.2	(0.5-2.4)	1	0.7	1.5	(0.0-8.1)	0	0.5	0.0	(0.0-7.7)
Leukemia	35	24.5	1.4	(1.0-1.9)	4	1.9	2.1	(0.6-5.3)	5	1.6	3.2	(1.0-7.5)
Other lymphatic and hematopoietic tissue	19	15.4	1.2	(0.7-1.9)	1	1.3	0.8	(0.0-4.4)	0	1.0	0.0	(0.0-3.7)

* CNS, central nervous system.

APPENDIX G

Wood River Refinery Employees Who
Worked for Fewer than Six Months

Mortality patterns among white men:

There were 2,042 white men who had worked for fewer than six months at the refinery. Vital status ascertainment was complete for 1,883 (92%) of these men. Table G1 displays the observed and expected numbers of deaths from selected causes among white men employed for fewer than six months. There were non-statistically significant excesses of deaths from all causes (507/486.9; SMR=1.0), all cancers (113/102.4; SMR=1.1), diabetes mellitus (10/6.7; SMR=1.5), diseases of the respiratory system (34/27.9; SMR=1.2), and benign neoplasms (4/1.5; SMR=2.7).

These short-term workers also experienced a statistically significant excess of lung cancer (50/35.0; SMR=1.4, 1.1-1.9) and slight excesses of cancers of several other organs including the liver (3/2.0; SMR=1.5), bladder (5/2.6; SMR=1.9) and leukemia (7/4.0; SMR=1.7) (table G2). None of the latter excesses was statistically significant.

Of the seven men who died of leukemia, all were hourly, and all but one were hired in the 1940s (table G3). Three of the seven had acute myelocytic leukemia, two had chronic myelocytic leukemia, one had acute lymphocytic leukemia and one had unspecified lymphocytic leukemia. Two of these men (cases 53 and 55) actually worked for less than one day at the refinery.

Mortality patterns among white women:

There were 286 white women who had worked for fewer

than six months at the refinery. Vital status was determined for 230 (80%) of them. There were 18 observed compared with 27.9 expected deaths, with SMRs of 0.6 for all causes and 0.7 (6/8.7) for all cancers. No striking excesses of specific diseases were observed among these women, and there were no deaths from leukemia.

Table G1

Observed and expected numbers of deaths and SMRs
for selected causes among 2,042 white men employed
for fewer than 6 months at the Wood River Refinery

Cause of death	Obs	Exp	SMR	(95% CI)
All causes	507*	486.9	1.0	(1.0-1.1)
All cancers	113	102.4	1.1	(0.9-1.3)
Infective and parasitic diseases	6	7.6	0.8	(0.3-1.7)
Benign neoplasms	4	1.5	2.7	(0.7-7.0)
Diabetes mellitus	10	6.7	1.5	(0.7-2.7)
Diseases of the blood and blood forming organs	0	1.2	0.0	(0.0-3.1)
Diseases of the nervous system	1	4.8	0.2	(0.0-1.2)
Diseases of the circulatory system	222	235.5	0.9	(0.8-1.1)
Diseases of the respiratory system	34	27.9	1.2	(0.8-1.7)
Diseases of the digestive system	20	25.4	0.8	(0.5-1.2)
Diseases of the genito- urinary system	7	6.2	1.1	(0.5-2.3)
Senility and ill defined conditions	5	5.4	0.9	(0.3-2.2)
All external causes	49	55.6	0.9	(0.7-1.2)
Other known causes	2	5.4	0.4	(0.0-1.0)

* Includes 33 deaths for whom the death certificate and cause of death were not available.

Table G2

Observed and expected numbers of deaths and SMRs
for selected cancers among 2,042 white men employed
for fewer than 6 months at the Wood River Refinery

Cancer site	Obs	Exp	SMR	(95% CI
All sites	113	102.4	1.1	(0.9-1.3)
Buccal cancer & pharynx	1	3.3	0.3	(0.0-1.7)
Esophagus	2	2.4	0.8	(0.1-2.0)
Stomach	3	4.7	0.6	(0.1-1.9)
Large intestine and rectum	12	11.8	1.0	(0.5-1.7)
Liver	3	2.0	1.5	(0.3-4.4)
Pancreas	4	5.4	0.7	(0.2-1.9)
Larynx	2	1.5	1.3	(0.2-4.7)
Lung	50	35.0	1.4	(1.1-1.9)
Skin	1	2.0	0.5	(0.0-2.8)
Bladder	5	2.6	1.9	(0.6-4.4)
Kidney	1	2.6	0.4	(0.0-2.1)
CNS*	1	3.5	0.3	(0.0-1.6)
Lymphosarcoma	3	2.1	1.4	(0.3-4.2)
Hodgkin's disease	1	1.4	0.7	(0.0-4.1)
Leukemia	7	4.0	1.7	(0.7-3.6)
Other lymphatic and hematopoietic tissue	1	2.6	0.4	(0.0-2.1)
Other and unknown sites	16	15.5	1.0	(0.6-1.7)

* CNS, central nervous system.

Table G3

Characteristics of leukemia deaths among white
men employed for fewer than six months at the
Wood River Refinery

Case no.	Year of Death	Age at Death	ICD* Code	Employment dates	Job [†]
53	1950	31	2050	1943-1943	EH
52	1955	50	2051	1943-1943	EH
51	1965	52	2040	1951-1952	EH
50	1976	79	2051	1945-1945	EH
49	1979	63	2050	1942-1942	EH
54	1981	81	2049	1944-1945	EH
55	1984	65	2050	1942-1942	EH

* ICD, International Classification of Diseases, Adapted for use in the United States, Eighth Revision (25).

† Job, job classification: EH=ever hourly.

APPENDIX H

Detailed Listing of Leukemia Deaths
Among Wood River Refinery Employees

Characteristics of Wood River Refinery
employees with leukemia

Case no.	Year of Death	Age at Death	ICD* Code	Employment dates	Jcb [†]
I. White men, leukemia reported as underlying cause of death					
42	1947	39	2079	1939-1947	EH
9	1950	42	2040	1933-1950	EH
1	1952	58	2040	1923-1949	EH
44	1953	46	2070	1935-1947	NPR
13	1954	62	2049	1927-1952	EH
16	1954	62	2041	1938-1950	PR
39	1955	42	2071	1939-1955	EH
5	1956	59	2049	1922-1952	EH
40	1957	41	2079	1939-1957	EH
41	1958	65	2079	1934-1953	EH
34	1959	38	2069	1947-1954	EH
22	1961	52	2050	1941-1961	EH
35	1962	66	2060	1923-1958	EH
32	1963	70	2060	1922-1949	EH
12	1965	72	2041	1925-1952	EH
3	1966	71	2041	1928-1956	EH
8	1966	45	2049	1953-1966	EH
33	1966	58	2060	1939-1963	EH
24	1967	43	2051	1947-1949	EH
7	1968	71	2049	1940-1944	EH
10	1968	61	2041	1926-1968	EH
6	1969	69	2049	1939-1944	EH
26	1973	51	2050	1956-1973	EH
14	1974	53	2040	1948-1974	PR
25	1974	62	2051	1937-1973	EH
29	1974	54	2050	1953-1955	NPR
17	1975	85	2050	1929-1951	EH
19	1975	54	2050	1942-1946	EH
30	1976	70	2050	1935-1965	NPR
36	1976	77	2060	1937-1943	PR
27	1977	75	2050	1923-1963	EH
31	1977	76	2050	1942-1961	EH
37	1977	62	2069	1941-1970	PR
2	1978	70	2041	1944-1945	EH
4	1978	65	2041	1943-1974	EH
21	1978	59	2050	1940-1977	EH
23	1979	74	2050	1942-1951	EH
38	1979	81	2070	1976-1957	EH
28	1981	73	2050	1942-1967	EH
20	1982	64	2050	1953-1977	EE
18	1983	70	2050	1951-1975	EE
43	1983	65	2070	1939-1955	NPR
11	1984	71	2041	1942-1975	EH
15	1984	69	2041	1945-1946	NPR

II. White men, leukemia reported as contributing cause of death[‡]

46	1953	61	2049	1927-1946	EH
45	1973	67	2079	1941-1942	EH
47	1976	51	2079	1947-1975	EH
48	1980	82	2041	1934-1945	EH
57	1968	49	2050	1941-1946	EH
58	1968	59	2079	1936-1947	EH

III. White woman

56	1981	52	2051	1952-1952	NPR
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* ICD, International Classification of Diseases, Adapted for use in the United States, Eighth Revision (25).

[†] Job, job classification: EH = ever hourly; PR = staff, production-related; NPR = staff, nonproduction-related.

[‡] Underlying cause of death (ICD code):

case no. 46 = 1030 (tuberculous meningitis)
case no. 45 = 5321 (perforated duodenal ulcer)
case no. 47 = 5820 (uremia)
case no. 48 = 4123 (Arteriosclerotic heart disease)
case no. 57 = 2090 (chronic myelofibrosis)
case no. 58 = 2090 (myelofibrosis).