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Cancer Mortality Patterns by Work Category in Three Texas Oil Refineries

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A previous proportionate mortality ratio analysis revealed elevated mortality from brain tumors, stomach cancer, leukemia, and other cancers among OCAW members employed in three Texas oil refineries. In order to evaluate these findings, complete work histories of cases and a matched set of controls who died from other causes of death were obtained from company personnel records. Work histories were summarized by classifying each job title and department entry into one of several broad work categories of refinery unit operations. A worker was considered "exposed" to a work category if he was known to have worked at least 1 day in the category 15 or more years prior to his death. Maximum likelihood estimates of the relative risk for brain tumor, stomach cancer, and leukemia were calculated by work category using a procedure for matched case-control data. No strong associations for brain tumor risk were seen with any work categories. A slight association for leukemia was seen among workers in the Treating category, which included unit operations that reduce the level of aromatic and sulfur constituents of petroleum products and combine them with additives to improve their quality. Stomach cancer risk was elevated among maintenance workers and workers exposed to lubricating oils and paraffin wax processing.

Key words: brain tumors, stomach cancer, leukemia, occupation, oil refining

INTRODUCTION

A proportionate mortality study of 2,132 deceased members of the Oil, Chemical, and Atomic Workers International Union (OCAW) employed in three Texas oil refineries indicated elevated proportionate mortality ratios (PMRs) for brain tumors, stomach cancer, and leukemia among white males (Table I) [Thomas et al, 1982]. Excess mortality from stomach cancer also occurred among nonwhite union members.

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PMRs were elevated for other hematopoietic and lymphatic malignancies and cancers of the skin, prostate, and pancreas. These results suggested the possibility of occupational risk factors. The present report is an evaluation of work histories of deceased active and retired union members who had worked at these refineries to determine whether deaths from brain tumor, stomach cancer, leukemia, or other selected neoplasms occurred with greater frequency than expected among employees in particular work categories.

MATERIALS AND METHODS

Study Subjects

Thirty-six deaths from brain tumor, 48 from stomach cancer, and 33 from leukemia were observed between 1947 and 1977 in the proportionate mortality study of active and retired deceased OCAW members who had worked at the three refineries [Thomas et al, 1982]. One brain tumor case, four stomach cancer cases, and four leukemia cases subsequently identified from records of active and retired deceased OCAW members were added to the original data for the present study. One leukemia case was eliminated from the study when additional information indicated that we had not obtained the correct death certificate.

Because the brain is a common site of metastases, hospital records and pathology reports were sought for each brain tumor case to corroborate death certificate diagnoses. Although many of the deaths occurred more than 15 years ago, hospital records were obtained for 28 of the 37 brain tumor cases. Six of the 37 cases were excluded from further analyses because the supporting diagnostic information available indicated that no brain tumor was present or that the brain was not the primary site.

For each male with brain tumor, stomach cancer, or leukemia, three deceased controls were selected from the active and retired union members who had worked at the same refinery, were of the same race and sex, and died of causes other than those being investigated. The selected controls were those who matched as closely as possible on age at death, date of death, and date of first membership in the union. Complete work histories for each case and control were requested from the three companies. Records were not located for two leukemia cases; thus, these cases and their matched controls were eliminated from the study. Records for 16 controls were not located, necessitating selection of substitute controls. Records for eight substitute controls could not be obtained and they were eliminated from the study. Thirty-one

TABLE I. Distribution of Cases of Brain Tumor, Stomach Cancer, and Leukemia by Refinery

		Brain tumor		Stomach cancer		Leukemia	
		Cases	Controls	Cases	Controls	Cases	Controls
Refinery A		17	51	20	60	10	28
Refinery B		9	27	23	69	16	48
Refinery C		5	15	9	25	8	20
Total		31	93	52	154	34	96
Original PMR (1)	White	2.11*		1.41*		1.89*	
	Nonwhite	1.25[a]		1.96*		1.25[b]	

[a]Based on one death—includes malignancies only.
[b]Based on two deaths.
*Statistically significant at the 0.05 level.

brain tumor, 52 stomach cancer, and 34 leukemia cases and their matched controls were included in the final analyses.

Work histories were also obtained for cases of multiple myeloma (N = 9), Hodgkin's disease (N = 9), non-Hodgkin's lymphoma (N = 23), and cancers of the skin (N = 14), prostate (N = 51), and pancreas (N = 41). These cases were ascertained using identical procedures as described above. Individually matched controls were not selected for these cases because the pool of eligible controls was depleted. Instead, the controls chosen for brain tumor, stomach cancer, and leukemia were pooled and used to develop crude estimates of usual employment patterns within the refinery work categories. The work histories of these cases were reviewed for evidence of any unusual distribution by work category.

Work Category Classifications

The three refineries are located in the Beaumont/Port Arthur area of the Texas Gulf Coast and have been in operation since the discovery of oil in that region approximately 80 years ago. Although they are owned by different companies, operations at the refineries are very similar and include standard processes used to convert crude oil into fuels, motor oils, and various petrochemical products.

Work histories for each subject were summarized by categorizing the types of unit operations common to each of the refineries. The identification of the unit operations by categories was done according to the American Petroleum Institute (API) description of an "average" refinery [API, 1973]. The following mutually exclusive categories were created, and the refinery processes and unit operations included in each are shown in Figure 1.

Category 1 (crude oil). This category includes the "first-step" refining processes of distillation and cracking. Distillation separates crude oil into several basic streams: (a) wet gas and gasolines; (b) light naptha; (c) kerosene, gas oil, and middle distillates; (d) heavy gas distillates; and (e) reduced crude. Stream (a) is used to produce gasoline. Stream (b) is the raw material used by the Catalytic Reforming Unit to produce gasoline as well as middle distillates used by processes in Category 3. Stream (c) is the raw material used by one of the processes in Category 3. Stream (d) is sent to the Catalytic Cracking Unit which produces "cracked" gasoline used in Category 3. The Vacuum Distillation Unit processes stream (c) to produce heavy gas oil used by the Catalytic Cracking Unit, lube stocks processed in Category 2, and solid residuum for Category 4.

Category 2 (lube oil). This category includes those "second-step" refining processes necessary to produce lubricating oils, paraffin wax, and raw materials for Category 5. Paraffin waxes are separated from lubricating oils in the Propane Dewaxing Unit and in the Solvent Dewaxing Unit which uses phenol, benzene, methyl-ethyl ketone, or toluene. Finishing processes include wax pressing and the blending of additives with lubricating oils after dewaxing.

Category 3 (treating). Gasoline, kerosene, light fuel oils, and diesel oils are produced by units classified into this category. Processes include blending of additives, hydrogen treating to remove sufur, alkylation to produce high-octane products, and polymerization to improve the quality of gasoline products.

Category 4 (coking). Solid residuums from the Vacuum Distillation Unit and other refining processes are used by units classified in this category to produce petroleum coke.

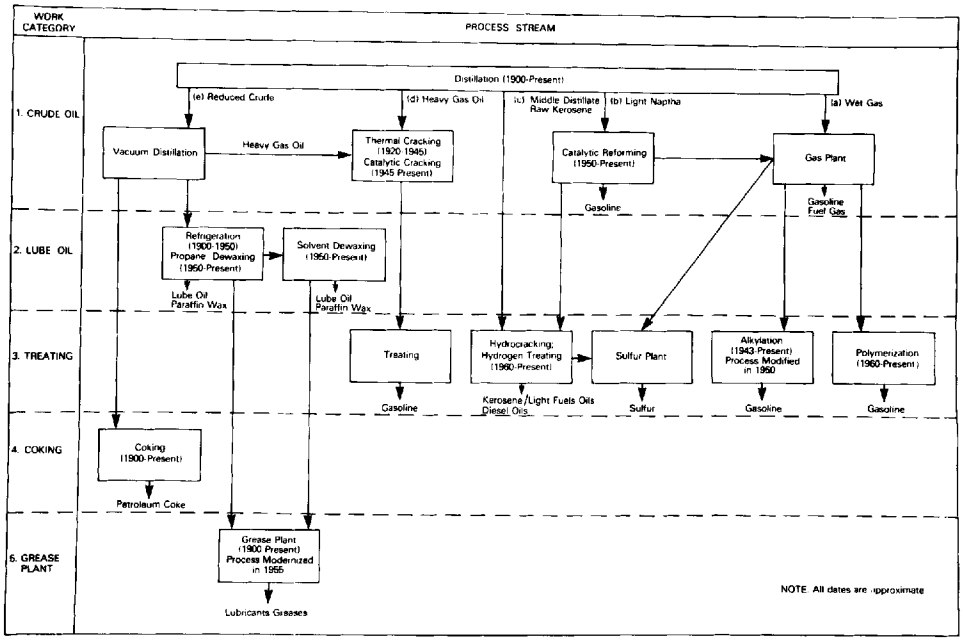

Fig. 1. Refinery processes by work category.

Category 5 (grease plant). In this category, lubricating oils are combined with soaps, detergents, and mineral additives to yield various industrial lubricants and greases.

Category 6 (utilities). This category includes all service processes for the refinery providing air, water, steam, and electricity as well as fire extinguishing.

Category 7 (maintenance and labor). All equipment servicing, maintenance, and construction functions involved in the refinery operations are classified into this category. The entry-level labor jobs often fall into this heterogeneous category, which employed most of the cases and controls for at least some time. Subcategories of pipefitting, boilermaking, welding, painting, machining, insulating, masonry, carpentry, still and tank cleaning, instrument maintenance, railway work, yard labor, construction, and miscellaneous maintenance activities were created to provide more specific exposure information. Most entry-level jobs were in the pipefitting and yard labor subcategories.

Category 8 (receipt and movement). This category includes processes, areas, and equipment used for receipt, shipment, storage, and intraplant pumping and transporting of bulk liquids (crude oil, oil products, and chemicals).

Category 9 (laboratory). Analytic testing of new products and quality control of materials used and produced by the refineries are included in this category.

Category 10 (motor transportation). Activities in this category include the servicing and operating of trucks and other vehicles used to transport refinery products.

Category 11 (other activities). This category includes office work, guard duties, cafeteria work, and other presumably "low-exposure" activities.

Although the unit operations described above represent the basic units of a large-size refinery (more than 100,000 barrels/day), many process changes have occurred within the refining industry over time. Some of these changes are designated in Figure 1.

Each job title and department entry in a study subject's work history was placed into one of these categories, but no quantitative exposure estimate to particular substances was attempted. If a department or unit was not listed, an attempt was made to classify the entry solely on the basis of job title. About 6% of the entries were unclassifiable and were treated separately as "unknown." The complexity of refinery operations and differences in departmental groupings between the companies made it difficult to establish a consistent category classification across the three plants.

The following inconsistencies were not resolved: First, refinery A had a packaging and shipping operation that was separate from the grease plant; therefore, grease packaging operations were not included in Category 5 for Refinery A but were classified into a separate category. Second, the Receipt and Movement category included all pump houses at Refinery C. However, owing to the departmental organization at refineries A and B, jobs in pump houses in the Crude Oil and Lube Oil areas were classified into Categories 1 and 2, respectively. Finally, separate classifications were made for the chemical divisions at Refineries A and B, the Compression Plant at Refinery A, and the Alchlor Unit, a water-treating unit, at Refinery B.

Because of the long latency period for most solid tumors, a worker was arbitrarily considered "exposed" to a work category if he was known to have worked at least 1 day in the category beginning 15 or more years prior to his death. Although the latency period for leukemia may be considerably shorter, changing the definition of an "exposed" worker by eliminating the latency period did not alter the results. The total number of days worked in a specific category was calculated for each "exposed" case and control. About 40% of the study subjects met the "exposure" requirements for only one category; some persons had "exposure" to as many as six categories. The average number of categories was two.

Statistical Analysis

Maximum-likelihood estimates of the relative risk (odds ratios) and 90% confidence intervals for brain tumor, stomach cancer, and leukemia were calculated by work category using Miettinen's procedure for matched case-control data with a variable matching ratio [Miettinen, 1975]. Odds ratios were calculated only for refinery work categories and subcategories of Category 7 in which five or more cases were identified as "exposed." Because of the skewed distributions for total duration worked in any of the various work categories, median durations were reported for those who were "exposed." Odds ratios were considered to be statistically significant if the 90% confidence interval did not include 1. The statistical significance testing used is not to be interpreted in the strict sense, but is to be used as a guide to the relative importance of the numerous comparisons made.

Trends by length of employment were examined utilizing the Mantel extension procedure [Mantel, 1963] for those categories in which the odds ratio was 1.5 or greater, the median duration of employment was greater for the cases than the controls, and the median duration of employment for the cases was greater than 5

years. Matching was dropped, and duration of employment levels were defined as the following: 1) not "exposed;" 2) "exposed" but worked less than 5 years in the category; 3) "exposed" and worked 5 years or more in the category. Standardized risk ratios were calculated for exposure levels 2 and 3, standardized to the lowest exposure level.

RESULTS

Table I shows the numbers of cases and controls ascertained from each refinery and PMRs computed in the original mortality study. PMRs for brain tumor, stomach cancer, and leukemia were significantly elevated among whites, and a significantly high mortality ratio for stomach cancer was also seen among nonwhites [Thomas et al, 1982].

The maximum-likelihood estimates of the odds ratios for brain tumor by refinery work categories are shown in Table II. Data for Maintenance and Labor subcategories are shown only for those in which at least 5 cases worked 1 day. The odds ratio of 1.6 seen among workers "exposed" to the Lube Oil category was not statistically significant. The median durations worked in this category were 1 year for the cases and 8 years for the controls. The odds ratio for brain tumor among workers employed in the Maintenance and Labor category was only slightly elevated. Within this category, there was an odds ratio of 1.5 for the subcategory of pipefitting, but the median duration worked by the cases was very brief and was less than that worked by the controls. Although a relative risk measure was not calculated for carpentry, four cases and only two controls worked there. A statistically significant odds ratio of 2.8 for brain tumor occurred among persons employed in the Receipt and Movement category; however, the median duration of employment for the controls was more than four times longer than that for the cases. There were insufficient numbers of cases employed in the Chemical Divisions at refineries A and B, Compression Plant at refinery A, or the Alchlor Unit at refinery B to justify separate analyses.

Results for stomach cancer by work category are presented in Table III. An elevated odds ratio for stomach cancer was seen among "exposed" workers in the Lube Oil category, and the median duration of employment for the cases was almost twice that for the controls. An odds ratio of 4.5 among persons employed in the Maintenance and Labor category was statistically significant. Cases employed in this category had a median duration of 6 years of employment compared with 4.5 years for the controls. The magnitude of this result could not be explained by an unusually high risk associated with any particular subcategory. Odds ratios for stomach cancer were elevated for several Maintenance and Labor subcategories, including pipefitting, boilermaking, painting, yard labor, and miscellaneous maintenance activities; however, median duration of employment for the cases was less than 2 years for all subcategories except painting (18 years). Although odds ratios were not calculated for the Laboratory category because of the small number of exposed cases, there was a large difference between the cases and controls in the median years worked (12 years for the cases vs 1 year for the controls). The odds ratio for stomach cancer was also elevated among workers in the Motor Transportation category, but the median duration employed was shorter for the cases than for the controls.

Odds ratios for leukemia (Table IV) were elevated only among persons who had been "exposed" to the Treating category and boilermaking. Neither result was

TABLE II. Number Employed at Least 1 Day, Median Duration of Employment, and Odds Ratios for Brain Tumor by Refinery Work Category, 15 Years Latency

Work category	Cases		Controls			
	No. employed at least 1 day	Median duration employed (years)	No. employed at least 1 day	Median duration employed (years)	Odds ratio	90% Confidence interval
01 Crude oil	5	13.1	22	8.4	0.6	0.2–1.5
02 Lube oil	9	1.0	20	8.2	1.6	0.7–3.5
03 Treating	0	—	6	19.0	—	—
04 Coking	0	—	0	—	—	—
05 Grease plant	0	—	11	1.9	—	—
06 Utilities	2	12.9	16	2.0	—	—
07 Maintenance and labor	23	11.8	67	11.6	1.2	0.4–3.1
Pipefitting	14	0.6	36	1.6	1.5	0.6–3.5
Yard labor	10	0.4	31	0.6	0.9	0.4–2.3
08 Receipt and movement	7	3.0	9	13.8	2.8	1.1–6.8
09 Laboratory	2	14.5	1	34.8	—	—
10 Motor transportation	1	0.3	6	4.4	—	—
11 Miscellaneous	2	2.7	8	0.9	—	—
Total (any category)[a]	31	25.4	93	25.9	—	—

[a]Numbers for specific categories do not equal total due to overlapping classifications for some study subjects.

TABLE III. Number Employed at Least 1 Day, Median Duration of Employment, and Odds Ratios for Stomach Cancer by Refinery Work Category, 15 Years Latency

Work category	Cases		Controls			
	No. employed at least 1 day	Median duration employed (years)	No. employed at least 1 day	Median duration employed (years)	Odds ratio	90% Confidence interval
01 Crude oil	9	9.4	51	14.8	0.4	0.2- 0.8
02 Lube oil	19	7.6	40	3.7	1.7	1.0- 3.1
03 Treating	4	6.9	14	1.6	—	—
04 Coking	2	3.0	6	1.8	—	—
05 Grease plant	8	4.2	25	1.5	0.9	0.4- 2.0
06 Utilities	6	2.2	24	4.4	0.7	0.3- 1.6
07 Maintenance and labor	47	6.0	119	4.5	4.5	1.7-12.0
Pipefitting	27	1.2	69	1.1	1.8	0.9- 3.7
Boilermaking	6	0.9	13	2.3	1.5	0.6- 3.6
Painting	5	18.3	14	0.2	1.1	0.4- 2.3
Yard labor	23	1.3	49	0.8	2.4	1.2- 4.8
Construction	6	0.2	16	0.3	1.2	0.4- 3.2
Miscellaneous	7	1.9	13	0.5	1.7	0.8- 3.9
08 Receipt and movement	5	14.9	16	11.2	0.9	0.4- 2.4
09 Laboratory	3	11.8	6	0.9	—	—
10 Motor transportation	7	1.5	13	2.9	1.7	0.7- 4.1
11 Miscellaneous	4	10.5	15	1.9	—	—
Total (any category)[a]	52	30.5	154	29.1	—	—

[a]Numbers for specific categories do not equal total due to overlapping classifications for some study subjects.

TABLE IV. Number Employed at Least 1 Day, Median Duration of Employment, and Odds Ratio for Leukemia by Refinery Work Category, 15 Years Latency

Work category	Cases		Controls		Odds ratio	90% Confidence interval
	No. employed at least 1 day	Median duration employed (years)	No. employed at least 1 day	Median duration employed (years)		
01 Crude oil	8	12.8	25	15.1	0.9	0.4–1.8
02 Lube oil	8	2.8	21	27.8	1.1	0.5–2.2
03 Treating	6	18.8	11	15.7	1.6	0.7–3.8
04 Coking	0	—	5	1.2	—	—
05 Grease plant	5	0.9	15	1.3	0.9	0.4–2.4
06 Utilities	2	13.3	11	12.5	—	—
07 Maintenance and labor	29	18.9	86	6.6	0.6	0.2–1.7
Pipefitting	19	2.5	59	1.6	0.6	0.2–1.5
Boilermaking	5	15.9	10	4.7	1.5	0.6–3.9
Yard labor	5	9.5	25	0.5	0.4	0.1–1.1
08 Receipt and movement	1	3.8	12	0.8	—	—
09 Laboratory	1	30.3	5	1.0	—	—
10 Motor transportation	3	1.4	8	1.6	—	—
11 Miscellaneous	3	0.3	14	3.0	—	—
Total (any category)[a]	34	28.2	96	31.8	—	—

[a]Numbers for specific categories do not equal total due to overlapping classifications for some study subjects.

statistically significant; however, in both situations the median duration of employment for the cases was greater than 15 years and was longer than that for the controls.

In the Mantel extension analysis, standardized risk ratios (SRRs) for stomach cancer increased with length of employment among workers in the Lube Oil and Maintenance and Labor categories (Table V). Although the SRR increased with duration employed in the Maintenance and Labor category, duration of employment was not sufficiently long in any one subcategory to explain the apparent association with employment in the Maintenance and Labor category. SRRs for leukemia increased with duration of employment in the Treating category and in boilermaking. None of the trends shown in Table V were statistically significant.

Table VI shows results by refinery for two of the categories showing a trend in Table V. Odds ratios for stomach cancer were elevated among Lube Oil category "exposed" persons employed at refineries A and B, and the odds ratio was statistically significant only for refinery A. No odds ratio was calculated for refinery C because of the small numbers. Odds ratios for stomach cancer among persons "exposed" to the Maintenance and Labor category were elevated for each of the three refineries but none were statistically significant. Results for leukemia were not analyzed by refinery because of the small number of cases employed at each refinery.

Compared with the pooled controls, no unusual distributions by work category were noted for the cases of multiple myeloma, Hodgkin's disease, non-Hodgkin's lymphoma, or cancers of the skin, prostate, and pancreas.

DISCUSSION

In this study, we examined the relationship between cancer mortality and refinery work categories using detailed work histories from three oil refineries in

TABLE V. Mantel Extension Analysis for Duration of Employment in Refinery Work Categories

	Duration of employment		
	0	1 day–5 years	5+ years
Stomach cancer			
Lube oil			
Cases	33	9	10
Controls	114	21	19
SRR[a]	1.0	1.5	1.8
Maintenance and labor			
Cases	5	22	25
Controls	35	63	56
SRR	1.0	2.4	3.1
Leukemia			
Treating			
Cases	28	2	4
Controls	85	5	6
SRR	1.0	1.2	2.0
Boilermaking			
Cases	29	2	3
Controls	86	5	5
SRR	1.0	1.2	1.8

[a]Standardized risk ratio.

TABLE VI. Number Employed at Least 1 Day and Odds Ratio for Stomach Cancer by Refinery for Selected Work Categories, 15 Years Latency

Work category	No. employed at least 1 day		Odds ratio	90% Confidence interval
	Cases	Controls		
02 Lube oil				
Refinery A	7	10	3.1	1.1- 8.8
Refinery B	10	23	1.5	0.7- 3.5
Refinery C	2	7	—	—
07 Maintenance and labor				
Refinery A	18	48	3.6	0.6-19.6
Refinery B	21	56	2.4	0.7- 8.8
Refinery C	8	15	3.3	0.9-11.4

Texas. Certain limitations in the resources and methodology must be considered when interpreting results. First, a few differences in job and departmental organization between the three refineries could not be resolved in classifying record entries into work categories. Changes in refinery operations, technology, departmental organization, and job classifications have varied over time and may have introduced additional classification inaccuracies. Second, it is not clear whether our work categories were truly indicative of exposure since the number of potential exposures in any particular category was extensive, and because workers may have had contact with a specific substance in more than one category. Third, there was a great deal of job mobility in each refinery and many of the study subjects were classified as "exposed" in multiple work categories. For example, the majority of brain tumor and stomach cancer cases "exposed" to other categories with elevated odds ratios had also worked in the Maintenance and Labor category. On the other hand, there was virtually no overlap between "exposure" to Treating and Boilermaking among the leukemia cases and their matched controls (1 case, 0 controls). Fourth, the number of cases with each form of cancer was relatively small. Consequently, we knew that the likelihood of detecting an elevated risk for a particular cancer was poor unless the actual risk was very high. Fifth, our comparisons were made between cases and matched controls all of whom worked at oil refineries, so that we may have overmatched with respect to general occupational exposures within the refinery environment. Finally, because we are making multiple comparisons, a number of statistically significant results would be expected due to chance.

Using the work categories defined for this study, elevated odds ratios for brain tumor were seen among OCAW members employed in the Lube Oil, Receipt and Movement, and pipefitting activities; however, the shorter duration of employment for the cases compared to the controls is not consistent with an etiologic role for occupational exposures in these particular categorizations. If long-term refinery workers in general have an elevated risk of brain tumors due to some diffuse exposure within the plant, for example, polycyclic aromatic hydrocarbons (PAHs) [Wen et al, 1981; Schottenfeld et al, 1981], the within-plant case-control method would not be effective in uncovering such a risk. Brain tumors have been induced experimentally by certain PAHs [Hosobuchi and Ishii, 1967; Zimmerman and Arnold, 1941, 1943], and small excess risks have been suggested among other occupational groups exposed

to PAHs, including aluminum reduction workers [Milham, 1976, 1979] and motor vehicle examiners [Stern et al, 1981].

The most intriguing associations found in this study were those between stomach cancer and employment in the Lube Oil and Maintenance and Labor categories. A positive relationship by length of employment was seen for both categories. Excessive mortality from stomach cancer among refinery workers has been reported in some studies [Thomas et al, 1982; Hanis et al, 1979] but not others [Schottenfeld et al, 1981; Theriault and Goulet, 1979; Hanis et al, 1982; Alderson and Rushton, 1982]. None of these studies reported patterns for Lube Oil workers separately. The basic process in the Lube Oil area is the separation of lubricating oil from petroleum waxes. Prior to the 1950s, this process involved the refrigeration of lube oil stocks and removal of solidified wax by filter pressing, a process previously related to nonmelanoma skin cancer [Hendricks et al, 1959]. About 1950, a solvent dewaxing process replaced the previous system. Among "exposed" study subjects employed in the Lube Oil category for more than 5 years, eight of ten cases (80%) and only 12 of 19 (63%) controls had worked in areas producing or packing paraffin wax. Most of the stomach cancer cases who were employed more than 5 years in the Lube Oil area had worked prior to 1950 in areas where paraffin wax was being separated from lubricating oils or prepared for packing. Although no expected value was calculated, three stomach cancers were observed among a cohort of 82 wax pressman studied between 1937 and 1956 [Hendricks et al, 1959]. Cancer of the stomach has also been associated previously with presumed exposures to lubricating oil mists in machining operations [Decoufle, 1978; Jarholm et al, 1981] and other occupations [Okubo and Tsuchiya, 1974], particulates such as carbon black among rubber workers [McMichael et al, 1976; Monson and Nakano, 1976], and with exposures to PAHs among roofers [Hammond et al, 1976]. No such relationship has been seen among other occupational groups exposed to PAHs including coke oven workers [Redmond et al, 1976] and coal gas workers [Doll et al, 1972]; however, a variety of PAHs given orally to rodents induced stomach tumors [Santodonato et al, 1981].

The relationship between stomach cancer and Maintenance and Labor activities may reflect exposures to petroleum stocks and products, or to asbestos. Maintenance work is generally characterized by high intermittent exposures that occur during shutdowns and problem situations. Elevated odds ratios for stomach cancer among pipefitters and boilermakers suggest the role of asbestos exposure, previously associated with stomach cancer risk [Miller, 1978].

No significant associations for leukemia occurred with any specific job category. The highest odds ratio occurred in the Treating category, which also showed a positive relationship with duration of employment. During treating, petroleum products are further refined by reducing the level of aromatic and sulfur constituents and are combined with additives to improve their quality. Although benzene exposure, previously associated with leukemia risk [Vigliani and Saita, 1964], was an a priori hypothesis, that exposure is not category-specific. The association with boilermaking was not statistically significant, but this finding is consistent with results of a study of shipyard boilermakers [Beaumont, 1980].

In summary, our study failed to detect any strong associations between brain tumor risk and employment within refinery work categories. This might result from limitations of the occupational categorizations, small numbers, or a true absence of elevated risk. Because the refinery work categories defined here are not exposure-

specific, workers exposed to particular chemicals could have elevated risks of specific cancers regardless of the work categories to which they were allocated. A slight association was seen for leukemia risk among workers in the Treating category, and stomach cancer risk was elevated among maintenance men and workers exposed to lubricating oils and paraffin wax processing. Further research involving larger study populations and more detailed exposure classifications is needed to clarify the role of occupational determinants of these tumors in the petroleum industry.

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