Original article

Scand J Work Environ Health 1986;12(6):552-560

doi:10.5271/sjweh.2101

Mortality among production workers in pulp and paper mills.

by Robinson CF, Waxweiler RJ, Fowler DP

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/3823804

Scand J Work Environ Health 12 (1986) 552—560

Mortality among production workers in pulp and paper mills

by Cynthia F Robinson, PhD,[1] Richard J Waxweiler, PhD,[1] Douglas P Fowler, PhD[2]

ROBINSON CF, WAXWEILER RJ, FOWLER DP. Mortality among production workers in pulp and paper mills. *Scand J Work Environ Health* 12 (1986) 552—560. A cohort of 3 572 pulp and paper mill workers employed for at least one year between 1945 and 1955 was followed through 31 March 1977. Vital status was determined for 99 % of the cohort. The 915 deaths observed were 79 % of the number expected on the basis of comparable United States mortality rates. Statistically nonsignificant excesses of deaths due to lymphosarcoma and reticulosarcoma and to stomach cancer were observed. These findings tend to corroborate reports based on state vital statistics, and preliminary case-referent and population-based studies of workers in the pulp or paper industries. No deaths due to nasal cancer were observed, but only 0.6 were expected. When process-specific analyses were conducted, the excess risk of lymphosarcoma and reticulosarcoma was increased only for men who worked in sulfate mills. The excess risk of stomach cancer was limited to men who worked in sulfite mills. Process-specific standardized mortality ratios for these causes were highest after 20 years since first employment in the mills.

Key terms: formaldehyde, lymphosarcoma, occupational health, pentachlorophenol, stomach cancer, wood dust.

Of approximately 600 000 people currently employed in the paper and allied products industry in the United States (US), 155 000 are production workers in pulp, paper, or paperboard mills (28). The industry has two distinct process stages: wood pulping and paper making. Both may be contained within one mill or may take place in separate locations, depending upon supplies of wood and water. This large industry may involve occupational exposures to sulfur compounds, chlorine, chlorine dioxide, lime, caustic soda, soda ash, alum, pigments, metallic dusts, paper and other dusts, and various other potentially toxic chemicals in addition to the suspect human carcinogen wood dust (14) and the known animal carcinogen formaldehyde (15).

Suspicions that workers in the pulp and paper industry might be at increased risk for several site-specific malignancies, particularly of the lymphatic and hematopoietic system, were initially raised by analyses using state vital statistics data (20, 21, 22). In addition, in US counties with pulp or paper manufacturing industry, there tended to be elevated rates of oral (2) and lung cancer (1, 12, 19) among males (table 1).

Few detailed analytic studies of pulp and paper mill workers have been published. In a large multitumor-site case-referent study, Decoufle et al (21) found that men who had worked as operatives in the paper industry for five years or more had an increased relative risk for lymphoma, multiple myeloma, leukemia, and malignancies of the buccal cavity, pharynx, larynx, stomach, prostate, kidney, colon, rectum, and lung. However, unevaluated hospital referral patterns may have contributed unknown biases.

In the only published retrospective cohort mortality study of workers in a pulp and paper mill, Ferris et al (6) followed for 10 years a cohort of 271 pulp and paper mill workers identified as actively working in the mill in 1963. Although only 33 deaths occurred among these workers by 1973, the 33 deceased paper and pulp mill workers were reported to have an overall standardized mortality ratio of 126. No cause-specific expected deaths were computed, the period of observation was short, and there was a substantial lack of statistical power.

Because of these associations between various malignancies and pulp and paper mill employment, we conducted a retrospective cohort mortality study of men employed in five pulp and paper mills located in the northwestern part of the United States. Our study was designed to evaluate the chronic health effects of employment in this industry and to test the hypotheses of increased mortality due to malignancies of the buccal cavity, pharynx, stomach, intestine/rectum, larynx, lung, prostate, bladder, kidney, and the hematopoietic and lymphatic systems (table 1), as well as that due to coronary heart disease and diseases of the blood-forming organs (20, 21).

Description of industry

Two chemical processes, sulfate (or Kraft) and sulfite, and one mechanical process, groundwood, were dominant in the pulp industry in the United States during the study period. In 1950 approximately 25 % of the 260 active US woodpulp mills used the sulfate process, 23 % used the sulfite process, and 35 % were

[1] National Institute for Occupational Safety and Health, Cincinnati, Ohio, United States.
[2] SRI International, Menlo Park, California, United States.

Reprint requests to: Dr CF Robinson, National Institute for Occupational Safety and Health, DSDTT/DBBS, Mail Stop C-32, 4676 Columbia Parkway, Cincinnati, Ohio 45226, USA.

Table 1. Previously reported associations[a] between paper-related industries and site-specific cancers.

Type of cancer	Pulp and paper	Sawyers, sawmills or logging
Buccal and pharynx	Blot & Fraumeni (2), Decoufle et al (4)	.
Stomach	Decoufle et al (4), Milham (21), Registrar General (24, 25, 26)	Guralnick (10), Milham (20, 21), Registrar General (24)
Intestines, rectum	Decoufle et al (4), Milham (20, 21)	Milham (20)
Larynx	Decoufle et al (4), Milham (20, 21)	Milham (21)
Lung	Blot & Fraumeni (1), Decoufle et al (4), Harrington et al (12), Menck & Henderson (19), Milham (21)	.
Prostate	Gallagher & Threlfall (8), McDonald (18), Milham (20, 21), Registrar General (23)	Guralnick (10), Milham (20)
Bladder	Milham (20)	Milham (20), Registrar General (26)
Kidney	Decoufle et al (4), Milham (20, 21)	Milham (20, 21)
Lymphoma, lymphosarcoma	Decoufle et al (4), Gallagher & Threlfall (8), Milham (20, 21), Registrar General (23)	Milham (20)
Hodgkin's disease	Milham (20, 21), Milham & Hesser (22)	.
Multiple myeloma	Decoufle et al (4), Milham (20, 21)	.
Leukemia	Decoufle et al (4), Milham (20, 21)	Milham (20, 21), Registrar General (25, 26)

[a] Relative risk greater than 1.2 or statistically significant.

groundwood mills. The remaining 17 % used various processes, principally soda and semichemical. In contrast, by 1974, the 349 active US mills were comprised of 11 % sulfite and 20 % groundwood processes, while the sulfate process had increased in use to 34 % of the total. The remaining 35 % was principally composed of the newer defibrated process and semichemical mills, with very few soda and chemimechanical process mills (7). Of the total US pulp production today, over 60 % is produced in sulfate mills, with less than 10 % accounted for by sulfite mills. Due to the changing technology, it was decided to study workers employed in the two major processes, ie, sulfate and sulfite.

The sulfate process, which is alkaline-based, depends mainly on pine wood (in the southern part of the United States) or fir (in the northwest mills studied). The acid-based sulfite process most commonly uses low resin woods such as spruce or hemlock, which contain hydroxyphenolic compounds. Almost any softwood can be used in the groundwood process; one of the sulfite mills in our study also ran a groundwood process which used both fir and hemlock (18).

Occupational exposures may arise at any stage in the process from preparation of the raw wood through the production of the final paper or pulp product (table 2). Wood preparation does not differ substantially for the several processes, but there can be significant differences in exposures in subsequent process steps, particularly in two areas, ie, in cooking liquor production and in pulp production, washing, bleaching and recovery, which together convert the wood fibers into cellulose fibers, ready for subsequent processing into paper of various grades or for direct sale as pulp.

Paper making often takes place in the same plant which produces the pulp, as was true for four of the five mills studied. The pulp is mixed with water and additives (if used) such as sizing agents (eg, formaldehyde compounds), fillers, and dyes. This slurry is formed into sheets and dried; then it may be coated, glazed, printed, and otherwise treated to complete the paper-making process.

Table 2. Pulp and paper mill exposures.

Production area or job	Potential exposures during study period
Raw wood preparation, ie, debarking and chipping	Wood volatiles, wood dust, (Douglas fir, hemlock), spores and fungi
Production of cooking liquor	Sulfate: ammonia, hydrogen sulfide, sulfur dioxide, mercaptans, chromates (as contaminants)
	Sulfite: sulfur, sulfur dioxide, calcium carbonate, zinc, sulfuric acid, lead fumes, asbestos, sulfurous acid
Pulp production, cooking	Sulfate: lime, magnesium, wood volatiles
	Sulfite: pigments, dyes, wood volatiles
	Groundwood: wood volatiles
Pulp bleaching and bleach plant	Chlorine compounds, boron compounds, caustic neoabietic acids
Wet pulp paper additives	Talc, clays, titanium dioxide, urea and melamine formaldehyde, pigments and dyes
Bleaching and additives	Same as for pulp bleaching, bleach plant and wet pulp paper additives
Paper rolling, sizing, dying, drying, glazing, coating	Urea and melamine formaldehyde, paper dust, coating and pigment dusts (aniline dye in the groundwood process plant)
Maintenance	General plant exposures
Unknown jobs, power and utility	General plant exposures
Unexposed jobs	No significant exposures

Subjects and methods

All 37 pulp and paper mills in the states of Washington, Oregon and California that were thought to have been in operation prior to 1950 were surveyed. Five pulp and paper mills were selected for study on the basis of the age of the mill, the completeness of the personnel records, and the type of process used by the mill. Of the five pulp and paper mills selected, three produced Kraft sulfate or sulfate pulp (which are essentially the same process) and two produced sulfite pulp. One of the two sulfite pulp mills also used the groundwood process, which is purely mechanical and involves no chemical treatment of the pulp. All five mills began pulp operations between 1918 and 1930. The end products of the study mills were newsprint, purified chemical cellulose, bleached and unbleached pulp, paper, board and boxboard. A different bleach process was used by each of the four mills which used bleach.

Before the pulp and paper mills were selected, the study cohort was defined to include only white males who worked at least one year between 1945—1955 inclusive. These criteria allowed the investigation to focus on persons with a minimum latency and whose follow-up would be facilitated due to their occupational stability and their having worked after World War II. Salaried office workers, females, and nonwhite males were excluded from the study due to their minimal exposures or small numbers. Employment records of the remaining men were microfilmed. The demographic data and the daily detailed work histories of each worker, including departments, job titles and dates, including layoffs, were coded for the computer from these records.

The 3 572 pulp and paper workers who met the study cohort criteria were followed from their last date of employment through 31 March 1977 (table 3). Vital status for 99 % of the study cohort was determined through records maintained by the Social Security Administration, the Internal Revenue Service, the state bureaus of motor vehicles, telephone directories, and other sources. Death certificates were obtained for 99 % of those deceased. Underlying causes of death were interpreted and coded by a nosologist according to the revision of the International Classification of Diseases (ICD) in effect at the time of death. Individuals with unknown vital status were assumed to be alive as of 31 March 1977. The 12 deceased individuals for whom no death certificate was available were assumed to be deceased, cause unknown.

Table 3. Vital status of paper and pulp mill workers in the northwest section of the United States as of 31 March 1977.

Vital status	Number	Percent
Alive	2 608	73
Deceased	915	25
With death certificate	903	99
Without death certificate	12	1
Lost to follow-up	49	1
Total workers (Total person-years 90 961)	3 572	100

A modified life-table technique (31) was used to obtain person-years at risk of dying by race and sex in five-year calendar-time periods, five-year age groups, five-year duration of employment periods, and five-year latency (time since first employment at the plant) periods. Person-years were multiplied by the appropriate US mortality rates to obtain the expected number of deaths.[3] Since the cohort was limited to white male production employees who had at least one year of employment between 1945 and 1955, person-years at risk began either at one year after first date of employment or on 1 January 1946, whichever came later.

Workers were included in a process subcohort analysis if they worked for one year or more in the appropriate process category. The sulfite process subcohort consisted of 1 779 men, and the sulfate subcohort of 1 796 men. It was possible for a person to be included in more than one process subcohort if he worked in more than one study mill; however only a few persons had worked longer than one year in each of the processes studied.

Because of the widespread interest in the health effects of formaldehyde, an additional subcohort of 1 262 men was examined separately. These men had worked 1 d or more in the areas of the mills believed to have had formaldehyde exposures (table 2). These areas were the paper-making portion of the mills, where urea and melamine formaldehyde resins were used (15). These resins were used in some of the sizing agents and pigments added to the slurry. They were also contained in some of the coatings applied to finished paper.

The observed numbers of deaths in the study cohort and subcohorts were compared with the numbers expected as derived from sex-, age-, race-, calendar-time-, and cause-specific US mortality rates. SMR values were calculated by dividing the number of observed deaths by the number of expected deaths and multiplying by 100. The SMR values were not calculated when the observed and expected numbers of deaths were both less than three. On the basis of our literature review, we developed a priori hypotheses for excess risks of death due to the malignancies listed in table 1, coronary heart disease and diseases of the blood-forming organs. Thus we decided to use one-sided testing of these causes of death at the 0.05 alpha level. We also wanted estimates of upper limits of risk. Consequently, we calculated two-sided 90 % confidence interval (90 % CI) values for the SMR values. An evaluation of the lower limit of these is equivalent to evaluation of the one-sided $p = 0.05$ test of excess risk. For consistency, similar

[3] Because appropriate comparison rates for lymphosarcoma and reticulosarcoma were not available before 1950, the rates from 1950—1954 were used for 1946—1949.

confidence intervals are presented for all SMR values in the paper. The Fisher exact method was used to calculate the intervals if the observed deaths were less than eight, and an approximate method was used if the observed number of deaths was eight or more (27).

Results

For the entire cohort (table 3), 90 961 person-years of observation were accrued. A statistically significant deficit of deaths was observed, 915 versus 1 150.3 expected (SMR 79) (table 4).

Mortality due to circulatory system disease (SMR 81) and all malignant neoplasms (SMR 76) was also statistically significantly below that expected. The SMR values for the following five site-specific malignancies were nonsignificantly elevated: stomach cancer (17 observed, 13.8 expected, SMR 123), prostate cancer (17 observed, 14.8 expected, SMR 115), kidney cancer (6 observed, 5.2 expected, SMR 115), bladder cancer (8 observed, 6.9 expected, SMR 116), and lymphosarcoma and reticulosarcoma (10 observed, 5.9 expected, SMR 169). All intestinal malignancies were of the colon; none were of the small intestine. Of the 10 deaths in the lymphosarcoma and reticulosarcoma category, nine (90 %) were due to lymphosarcoma, as opposed to 61 % observed in the US population for 1970 (29). There was a slight excess of deaths due to diseases of the blood-forming organs (5 observed, 3.0 expected, SMR 167). No deaths due to nasal cancers were found. In addition, a careful review of all 903 death certificates revealed no mention of sinonasal cancer as a contributory cause of death or other significant condition.

A detailed examination of the work histories of the 10 lymphosarcoma and reticulosarcoma cases revealed that four of the men worked in pulp production, two worked in raw wood preparation, two worked in maintenance, and two worked in paper-making areas. The bimodal age distribution of deaths was not unusual.

Only causes of death with elevated SMR values or those causes of death which were of interest because an excess risk had been observed in previous studies are presented in tables 6 and 7 for the process subcohorts. Among the subcohort of sulfite/groundwood process workers (table 6), significantly fewer deaths occurred than were expected, resulting in an SMR of 86. The SMR values were elevated, but were not statistically significant, for two site-specific malignancies, ie, stomach cancer (11 observed, 7.4 expected, SMR 149) and kidney cancer (4 observed, 2.7 expected, SMR 148). The few deaths due to diseases of the blood and blood-forming organs were more than expected (3 observed, 1.6 expected).

There were 392 deaths among the subcohort of men employed in pulp and paper mills (table 7) which used Kraft or sulfate pulping processes, whereas 544.1 deaths were expected, resulting in a significantly decreased SMR of 72. The SMR for all malignant neoplasms was also 72 % of that expected. However, there was a twofold excess (90 % CI 90—408) due to lym-

Table 4. Cause-specific deaths among white males employed in five northwest pulp and paper mills.

Cause of death[a]	Observed deaths	Expected deaths	Standardized mortality ratio	90 % confidence limits
Malignant neoplasms (140—205)	160	211.5	76	66—86
Buccal cavity and pharynx (140—148)	1	7.0	14	0—68
Digestive system (150—159)	42	64.9	65	49—84
Stomach (151)	17	13.8	123	78—185
Intestines (152, 153)	7	19.7	35	17—67
Pancreas (157)	4	11.9	34	11—77
Nasal (160)	—	0.6	.	.
Larynx (161)	3	3.3	91	25—235
Lung (162—163)	50	62.1	81	63—102
Prostate (177)	17	14.8	115	73—172
Kidney (180)	6	5.2	115	50—228
Bladder (181)	8	6.9	116	58—209
Brain (193)	4	6.3	63	21—145
Lymphosarcoma and reticulosarcoma (200)	10	5.9	169	92—287
Hodgkin's disease (201)	1	2.7	.	.
Leukemia (204)	4	8.7	46	22—145
Other lymphatic (202, 203—205)	2	3.0	.	.
Diseases of the blood-forming organs (290—299)	5	3.0	167	66—350
Vascular lesions of the central nervous system (330—334)	72	85.1	85	69—103
Diseases of the circulatory system (400—468)	432	532.1	81	75—88
Nonmalignant respiratory disease (470—527)	52	62.7	83	65—105
Accidents (800—962)	72	73.6	98	80—119
Residual causes, unknown	122	182.3	67	57—78
Total	915	1 150.3	79	75—84

[a] Code of the International Classification of Diseases, seventh revision, in parentheses.

phosarcoma and reticulosarcoma (6 observed, 2.9 expected, SMR 207). Only lymphosarcoma was found among the sulfate workers; no reticulosarcoma deaths occurred. A slight excess mortality occurred due to cancer of the prostate (8 observed, 6.7 expected, SMR 119) and cancer of the bladder (4 observed, 3.2 expected, SMR 125).

Mortality due to lymphosarcoma among the sulfate process workers and mortality due to stomach cancer among the sulfite process workers, as well as mortality due to prostate and urinary tract cancer among the entire cohort, were further analyzed by duration of employment and latency. The excess risk of mortality due to lymphosarcoma among the sulfate process workers was the most evident only after 20 years' latency and employment (4 observed, 1.1 expected, SMR 364) (table 8). The stomach cancer risk among the employees of the sulfite pulp mills (table 9) was also the most elevated after a 20-year latency period (9 observed, 5.1 expected, SMR 176), but during that latency period did not increase with duration of employment.

Among the pulp and paper workers employed over 20 years, excesses of prostate cancer (11 observed, 7.0 expected, SMR 157) and urinary tract cancer (9 observed, 5.5 expected, SMR 164) were evident. Among those with greater than 30 years' latency, excesses were seen for prostate cancer (12 observed versus 6.9 expected) and urinary tract cancer (8 observed versus 4.4 expected). These excesses were independent of process.

Among the subcohort which had worked in production areas with potential formaldehyde exposure, there were 286 deaths, whereas 400.5 were expected (SMR 71). No excess risks of death for any malignancies were found except for urinary tract cancer (4 observed versus 1.0 expected, SMR 400) after 30 years' latency. Three of these deaths occurred within the last three years of follow-up. Their detailed work history records showed that all four of the men had worked in the paper-drying areas of the mills for 8, 17, 25, and 30 years, respectively. Two had worked in sulfite mills, and the other two had worked in sulfate mills.

Table 5. Detailed work histories of workers who died of lymphosarcoma and reticulosarcoma by pulp process.

Latency (years)	Area or job	Dates worked	Age (years) at death
Sulfate mills			
34	Paper machine area Laboratory	1943—1949 1949—1967	71
31	Paper machine area	1935—1966	51
31	Pulp production area No information on record Unexposed area	1944—1947 1947—1961 1964—1966 1961—1964	74
26	No information on record Pulp production area	1947—1955 1955—1973	63
22	Maintenance/millwright Leaves of absence	1946—1968 1947, 1966	62
13	Yard labor	1952—1965	33
Sulfite mills			
37	Raw wood preparation area Maintenance	1937—1945 1941, 1945—1973	63
16	Pulp production area	1942—1955	68
9	Raw wood preparation area	1948—1957	30
2	No information on record	1947—1949	30

Discussion

The site-specific malignancies with the highest SMR values in this study included lymphosarcoma and re-

Table 6. Selected causes of death among workers in the pulp and paper mills which used the sulfite process.[a]

Cause of death[b]	Observed deaths	Expected deaths	Standardized mortality ratio	90 % confidence limits
All causes	523	605.4	86	80—93
All malignant neoplasms (140—205)	88	110.7	79	66—95
Buccal cavity and pharynx (140—148)	—	3.7	0	0—100
Stomach (151)	11	7.4	149	83—246
Intestines (152, 153)	5	10.4	48	19—101
Pancreas (157)	2	6.2	32	6—101
Nasal (160)	—	0.3	.	.
Larynx (161)	2	1.7	.	.
Lung (162—163)	26	32.0	81	57—113
Prostate (177)	9	8.1	111	58—194
Kidney (180)	4	2.7	148	51—339
Bladder (181)	4	3.7	108	37—247
Lymphosarcoma and reticulosarcoma (200)	4	3.0	133	45—305
Hodgkin's disease (201)	1	1.3	.	.
Leukemia (204)	3	4.5	67	18—172
Other lymphoma (202, 203—205)	1	1.5	.	.
Residual	17	24.3	70	45—105
Diseases of the blood-forming organs (290—299)	3	1.6	188	51—486

[a] Total person-years 44 976.
[b] Code of the International Classification of Diseases, seventh revision, in parentheses.

Table 7. Selected causes of death among workers in the pulp and paper mills which used the Kraft or sulfate processes.[a]

Cause of death[b]	Observed deaths	Expected deaths	Standardized mortality ratio	90 % confidence limits
All causes	392	544.1	72	66—78
All malignant neoplasms (140—205)	73	100.8	72	59—88
Buccal cavity and pharynx (140—148)	1	3.4	29	1—140
Stomach (151)	6	6.3	95	42—189
Intestine (152, 153)	2	9.3	22	4—68
Pancreas (157)	2	5.6	36	6—112
Nasal (160)	—	0.3	.	.
Larynx (161)	1	1.6	.	.
Lung (162—163)	25	30.1	83	59—215
Prostate (177)	8	6.7	119	59—215
Kidney (180)	2	2.5	.	.
Bladder (181)	4	3.2	125	43—290
Lymphosarcoma and reticulosarcoma (200)	6	2.9	207	90—408
Hodgkin's disease (201)	—	1.3	.	.
Leukemia (204)	1	4.2	24	1—113
Other lymphoma (202, 203—205)	1	1.4	.	.
Residual	13	22.1	59	35—94

[a] Total person-years 46 070.
[b] Code of the International Classification of Diseases, seventh revision, in parentheses.

Table 8. Observed (O) and expected (E) deaths due to lymphosarcoma by time since first employment and duration of employment among workers in the sulfate process. (SMR = standardized mortality ratio)

Latency	Duration of employment					
	Less than 20 years			Greater than 20 years		
	O	E	SMR	O	E	SMR
Less than 20 years	1	0.9	111	—	0	.
Greater than 20 years	1	0.8	125	4	1.1	364

Table 9. Observed (O) and expected (E) deaths due to stomach cancer by time since first employment and duration of employment among workers in the sulfite process. (SMR = standardized mortality ratio)

Latency	Duration of employment					
	Less than 20 years			Greater than 20 years		
	O	E	SMR	O	E	SMR
Less than 20 years	2	2.3	87	—	0	.
Greater than 20 years	4	1.7	235	5	3.4	147

Table 10. Detailed work histories of the sulfite mill workers who died of stomach cancer.

Latency (years)	Area or job	Dates worked	Age (years) at death
39	Raw wood preparation	1929—1932	66
	No information on record	1932—1942	
	Painter, maintenance	1942—1945, 1946—1966	
	Groundwood pulp production	1945—1946	
34	Groundwood pulp production	1934	64
	Wood mill, saw mill, yard	1940—1956	
33	Raw wood preparation	1930—1942, 1946—1955	51
	Military leave	1942—1946	
31	Raw wood preparation	1921—1946	70
24	Raw wood preparation	1938—1956	82
	Storekeeper	1956—1976	
6	Yard laborer, watchman	1944—1949	65
26	Paper making	1947—1955	75
25	Pulp production	1943—1958	74
32	Operator, engineer	1930—1962	59
9	Fuelman, fireman, power	1942—1951	60
27	Laborer	1934—1947	75

ticulosarcoma and cancer of the stomach and the urinary tract, all of which have been elevated in previous studies of workers in paper-related industries. Although none of these elevated values were statistically significant, this lack of significance could be due to the small numbers of deaths. Both the low background death rates of the causes of death of a priori interest and the small cohort size contributed to the problem of the small numbers of expected deaths for these causes. This problem is reflected in the wide confidence intervals observed for most of the SMR values in table 4. These intervals allow us to rule out any excess risk of death due to malignancies of the buccal cavity and pharynx, intestines, pancreas, and lung. However, we can only exclude the possibility of SMR values greater than 200—300 for all other malignancies of any a priori interest from table 1.

We were surprised by the strikingly low overall SMR of 79 in this group of pulp and paper workers, all of whom entered the cohort at least 22 years before the end of follow-up (table 4). This low SMR does not appear to be due to inadequate follow-up (1 %). To explore the effect of persons lost to follow-up on the calculation of expected deaths, we carried out an alternative analysis in which person-years at risk were terminated on the day the workers lost to follow-up quit work rather than assuming them to be alive at the end of the study. None of the SMR values calculated by

this alternative method differed by more than 1 % from those in table 4.

The cohort did not appear to be diluted by persons with limited duration of exposure or latency. To investigate this possibility, analyses were conducted for both process subcohorts which were stratified by latency and duration of employment. All the SMR values for the long latency and duration of exposure in the all-causes and all-malignant-neoplasms categories were within 5 % of the overall SMR values presented in tables 6 and 7. None of the SMR values was greater than 100.

The excess risk of death due to lymphosarcoma was greater among the workers in the sulfate process mills (SMR 207) than among those in the sulfite process mills (SMR 133). Among the workers in sulfate process mills, the increased SMR values for lymphosarcoma with long durations of employment and after 20 years since first employment were consistent with an hypothesized occupational etiology. A recent report of provincial mortality (8) based on death-certificate occupation reported statistically significant increased deaths due to lymphosarcoma and reticulosarcoma, as well as to prostate cancer, among Canadian pulp mill workers. However, industrial hygiene information on the work environment and type of pulping process was not reported.

While the excess risk in our study appeared to be restricted to sulfate mills, the lymphosarcoma cases do not seem to cluster in any particular work area. Despite the limitations of the environmental data, it remains noteworthy that many of the lymphosarcoma cases worked in areas with presumable exposure to wood volatiles, which may contain either neoabietic acids (16) or pentachlorophenols used for slime control (14). The latter have been linked to lymphomas by Hardell et al (11). The twofold elevated risk of death from lymphosarcoma among the sulfate workers was independent of the slightly elevated relative risks for lymphosarcoma reported by Milham (21) in a proportionate mortality analysis of pulp mill workers in the same geographic area of the United States. Only three of the ten deaths due to lymphosarcoma or reticulosarcoma in our study cohort were included in his analysis of state vital statistics. Because of the known relationship between immunosuppressive drug therapy and the subsequent development of lymphatic system cancers (16), the nine lymphosarcoma and one reticulosarcoma death certificates were examined for all contributory causes of death. However, no conditions which might require immunosuppressive drug therapy were mentioned on their death certificates.

The elevated SMR for stomach cancer may have been due to life-style factors, which were not controlled in the analyses. Studies have detected an increased incidence among men of lower socioeconomic status. In spite of possible confounding by socioeconomic status, evidence for a possible occupational association with pulp or paper mill employment is also provided by two other studies (4, 21).

The increased risk of dying from stomach cancer among the pulp and paper workers corroborates other studies of workers of such wood-related industries as the furniture, plywood, and sawmill and logging industries (10, 11, 20, 21, 24, 25), and among carpenters (20, 21). According to a recent report, the excess in paper and pulp workers appears to have declined over the last three decades (20). The possibility that these excess risks of stomach cancer are related to wood dusts either directly or indirectly as carriers of carcinogens needs to be evaluated by measurements of particle-size distributions and the modeling of respiratory and digestive system deposition patterns (5, 13). Six of the 11 men with stomach cancer in the sulfite/groundwood workers' subcohort had worked in areas of wood preparation (table 10), where log debarking and chipping into small pieces takes place (tables 2 and 10).

The fourfold excess of urinary tract cancer after 30 years' latency among those who worked in paper-drying areas with potential exposure to formaldehyde appears to warrant further investigation. Although at least one mill was believed to have used benzidene-based dyes, known urinary tract carcinogens, no exposure data were available at the mills. Levels of up to 2.5 ppm of formaldehyde (Stanford Research Institute project no 5847 report) have been found in these pulp mills. It is noteworthy that an excess risk of kidney cancer (a proportional mortality ratio of 256, based on 6 cases) has been reported among embalmers exposed to formaldehyde (30).

Two (2, 4) of several epidemiologic studies of pulp and paper mill workers have reported excess risks for dying of cancer of the buccal cavity, but a large deficit (1 observed, 6.6. expected) was observed in our study. A fourfold relative risk for oral and laryngeal cancer was observed by DeCoufle et al (4) among men who had worked as operatives in the paper industry for five years or more. In addition a significantly increased mortality rate for oral cancer was observed among white males by Blot & Fraumeni (2) for US counties with more than 1 % of the population employed in the paper industry.

The elevated rates we observed for lymphosarcoma, stomach cancer, and urinary tract cancer, while not statistically significant, were provocative because of the associations observed in earlier epidemiologic studies. These excesses do not appear to be due to differences between local and US mortality rates. In Washington State, where the mills are located, the mortality rates for lymphosarcoma, other lymphomas and mycosis fungoides; bladder cancer; and stomach cancer are all within 1 % of the respective US mortality rates (17).

A deficit of risk due to lung cancer was observed in this study (50 observed, 62.1 expected, SMR 81). Lung cancer has been associated with pulp and paper

mill employment in some studies (1, 12, 19) but not in others (3, 9). In the only study which considered cigarette smoking, a case-referent study of 535 male residents of coastal Georgia, no association was found with pulp or paper mills (3).

Conclusion

Statistically nonsignificant excesses of mortality due to lympho- and reticulosarcoma and stomach cancer were found in a cohort of pulp and paper mill workers. These findings tend to corroborate reports based on state vital statistics, as well as preliminary studies of pulp or paper mill workers which observed associations with lymphatic cancer. In our study, the lymphosarcoma excess was restricted to those who had worked in the sulfate mills, while the stomach cancer excess was limited to those who had worked in the sulfite mills. These process-specific SMR values were highest after 20 years since first employment in the mills. Although no etiologic agents were distinguishable, further research, including the continuing follow-up of this cohort and the characterization of exposure-response relationships, should be conducted. Future research should focus on the potential carcinogenic roles of exposure to wood dust, formaldehyde, sulfur compounds, and other chemicals in this industry.

Acknowledgments

The authors thank the pulp and paper mills and unions which participated in the study and the tripartite committee members. We thank Dr G Marsh for his biostatistical review, Dr S Milham, Jr, for his assistance with the death certificates and other aspects, and Dr JK Wagoner and Mr RA Lemen, who helped initiate the study. We acknowledge Dr W Gaffey for his contribution during the plant identification, data collection, and data reduction and the assistance of Ms A Winship-Ball and J Cohen at the Stanford Research Institute. We thank Mr P Bierbaum, Mr D Brown, and other NIOSH personnel who worked on the study, and the Southwestern Ohio Regional Computer Center, which assisted with the data reduction and analysis.

References

1. Blot WJ, Fraumeni JF Jr. Geographic patterns of lung cancer: Industrial correlations. Am J Epidemiol 103 (1976) 539—550.
2. Blot WJ, Fraumeni JF Jr. Geographic patterns of oral cancer in United States: Etiologic implications. J Chronic Dis 30 (1977) 745—757.
3. Blot WJ, Harrington JM, Toledo A, Hoover R, Heath CW Jr, Fraumeni JF Jr. Lung cancer after employment in shipyards during World War II. New Engl J Med 299 (1978) 620—624.
4. Decoufle P, Stanislawczyk K, Houten L, Bross IDJ, Viadana E. Retrospective survey of cancer in relation to occupation. US Government Printing Office, Washington, DC 1977. (DHEW (NIOSH) publication no 77—178: 146).
5. Dement JL, Harris RL. Estimates of pulmonary and gastrointestinal deposition for occupational fiber exposures. US Government Printing Office, Washington, DC 1979. (DHEW (NIOSH) publication no 79—135).
6. Ferris BG Jr, Puleo S, Chen HY. Mortality and morbidity in a pulp and a paper mill in the United States: A ten year follow-up. Br J Ind Med 36 (1979) 127—134.
7. Forest Products Laboratory. Woodpulp mills in the United States. Forest Service, US Department of Agriculture, Washington, DC 1977. (USDA forest service resource report FPL-1).
8. Gallagher RP, Threlfall WJ. Cancer risk in wood and pulp workers. In: Stitch H, ed. Carcinogens and mutagens in the environment. Volume 5. CRC Press Inc, Boco Raton, FL 1985.
9. Gottlieb MS, Pickle LW, Blot WJ, Fraumeni JF Jr. Lung cancer in Louisiana: Death certificate analysis. J Natl Cancer Inst 63 (1979) 1131—1137.
10. Guralnick L. Mortality by industry and cause of death. Vital Stat Spec Rep 53 (1963): 4, 369—370.
11. Hardell L, Eriksson M, Lenner P, Lundgren E. Malignant lymphoma and exposure to chemicals, especially organic solvents, chlorophenols and phenoxy acids, a case control study. Br J Cancer 43 (1981) 169—176.
12. Harrington JM, Blot WJ, Hoover RN, Housworth WJ, Heath CA, Fraumeni JF Jr. Lung cancer in coastal Georgia: A death certificate analysis of occupation. J Natl Cancer Inst 60 (1978) 295—298. (Brief communication).
13. Harris JRL. Aerodynamic considerations; what is a respirable fiber of fibrous glass? In: US Government Printing Office. Proceedings, NIOSH Symposium on Occupational Exposures to Fibrous Glass. Washington, DC 1974. (DHEW (NIOSH) publication no 76—151).
14. International Agency for Research on Cancer. Wood, leather and some associated industries. Lyon 1981. (IARC monographs on evaluation of the carcinogenic risk of chemicals to humans, volume 25).
15. International Agency for Research on Cancer. Some industrial chemicals and dyestuffs. Lyon 1982. (IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans, volume 29).
16. International Agency for Research on Cancer. Some antineoplastic and immunosuppressive agents. Lyon 1981. (IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans, volume 26).
17. Mason TJ, McKay FW. US cancer by county: 1950—1969. US Government Printing Office, Washington, DC 1979. (DHEW publication no (NIH) 79—1649).
18. McDonald RG, ed. Pulp and paper manufacture. Volumes I, II, III. McGraw Hill Book Company, New York, NY 1969.
19. Menck HR, Henderson BE. Occupational differences in rates of lung cancer. J Occup Med 18 (1976) 797—801.
20. Milham S Jr. Occupational mortality in Washington State 1950—1979. US Government Printing Office, Washington, DC 1983. (DHHS (NIOSH) publication no 83—116).
21. Milham S Jr. Occupational mortality in Washington State 1950—1971. US Government Printing Office, Washington, DC 1976. (DHEW (NIOSH) publication no 76—175 A, B, C).
22. Milham S Jr, Hesser JE. Hodgkin's disease in woodworkers. Lancet 2 (1967) 136—137.
23. Office of Population Censuses and Surveys. Occupational mortality: The Registrar General's decennial supplement for England and Wales 1970—72. Her Majesty's Stationery Office, London 1978.
24. Registrar General. Decennial supplement, England and Wales, 1951: Occupational mortality, part II, Volume 1 (Commentary). Her Majesty's Stationery Office, London 1958.
25. Registrar General. Decennial supplement, England and

Wales, 1951: Occupational mortality, part II. Volume 2 (Tables). Her Majesty's Stationery Office, London 1958.
26. Registrar General. Decennial supplement, England and Wales, 1961: Occupational mortality, tables. Her Majesty's Stationery Office, London 1971.
27. Rothman KJ, Boice JD Jr. Epidemiologic analysis with a programmable calculator. US Government Printing Office, Washington, DC 1979. (NIH publication no 79—1649).
28. US Bureau of the Census. Statistical abstract of the US. Washington, DC 1977, p 801.
29. US Department of Health, Education and Welfare. Vital statistics of the US 1970. Volume II, Part A. Hyattsville, MD 1973.
30. Walrath J, Fraumeni JF Jr. Proportionate mortality among New York embalmers. In: Proceedings of the third annual conference "Formaldehyde Toxicity," Hemisphere Publishing Corp, New York, NY (in press).
31. Waxweiler RJ, Beaumont JJ, Henry JA, Brown DP, Robinson CF, Ness GO, Wagoner JK, Lemen RA. A modified life table analysis system for cohort studies. J Occup Med 25 (1983) 2, 115—124.

Received for publication: 26 June 1986