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Risk of Lung Cancer Among Former Chromium Smelter Workers

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Hexavalent chromium is a known carcinogen. Previous epidemiologic studies in the 1950s of United States workers from seven facilities producing chromium compounds from chromite ore have reported a markedly increased risk for dying from lung cancer. As part of a high risk notification project of workers from four of these facilities, a mortality study was performed. The cohort was assembled in 1990–1991 from the Social Security records of four former chromate producing facilities in northern New Jersey. The study subjects were known to have worked at these facilities some time between 1937 and 1971. Proportionate mortality and proportionate cancer mortality ratios (PCMR) were calculated. The overall risk for lung cancer was a PCMR of 1.51 (confidence limits [CL] 1.29–1.74) for white men and 1.34 (CL 1.00–1.75) for black men. These risks increased with increasing duration of employment and latency since time of first employment. The PCMR for greater than 20 years duration of work and more than 20 years since first exposure was 1.94 (CL 1.15–3.06) for white men and 3.08 (CL 1.13–6.71) for black men. The risk for lung cancer for white men remains elevated more than 20 years after exposure has ceased (PCMR, 1.29; CL 1.03–1.60). The PCMR for nasal cavity/sinus cancer was also found to be a significantly increased, 5.18 (CL 2.37–11.30). A cluster of bladder cancer was seen among black workers from one facility, (PCMR, 3.30; CL 1.42–6.51). Despite the cessation of exposure, former chromium workers remain at significantly increased risk of lung cancer. Although there have been case reports of nasal cavity/sinus cancer in association with chromium exposure, this is the first epidemiologic study to report a significant increase in these cancers. Limitations in this study include lack of exposure data and lack of information on smoking habits. The lack of increase in other smoking-related diseases besides lung cancer indicates that the increase in lung cancer cannot be attributed to cigarette smoking. The ongoing elevated risk of lung cancer after cessation of exposure emphasizes the need for developing early detection tests for lung cancer.

KEY WORDS: hexavalent chromium, lung cancer, nasal cancer, sinus cancer, chromate production

INTRODUCTION

The carcinogenic potential of chromium compounds has been extensively reviewed [IARC, 1990; Norseth, 1981; Hayes, 1982; U.S. EPA, 1984; Langard, 1990, 1993]. The International Agency for Research on Cancer (1990) concluded that there was sufficient evidence that hexavalent chromium compounds were carcinogenic in humans. Risk estimates have ranged from a low of less than a 2-fold to a 30-fold increase of lung cancer.

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Case reports of lung cancer among chromate production workers were first reported in the German medical literature in the 1930s. The first health study of workers in the United States was reported in 1948 [Machle and Gregorius, 1948]. This study of workers in all the plants in the United States where chromates and bichromates were made from chromite ore (four in New Jersey, one in New York, one in Ohio, and one in Maryland) found that 22% of all deaths were due to cancer of the respiratory system. The Public Health Service studied these same plants in the early 1950s [Public Health Service, 1953]. A majority of the workers had perforated nasal septa (57%), and there was a 29-fold increase in deaths from respiratory cancer. Black workers had higher morbidity and mortality. Seventy-seven percent of the black workers had perforated nasal septa vs. 50% among white workers. There was an 80-fold increase in deaths from lung cancer among black workers vs. a 15-fold increase among white workers. The prevalence of smoking among black and white workers was similar, 84% and 81%, respectively. There were more heavy smokers among whites vs. blacks (32% vs. 12%).

More recent studies of the workers at the plant in Maryland have shown reduced risks of lung cancer with latter year of hiring [Hayes et al., 1979]. How much of the decreasing risk of lung cancer among workers in this plant with latter year of hiring can be attributed to improvements in working conditions with decreased exposure vs. how much can be attributed to an inadequate time since first exposure to evaluate the full risk of lung cancer among more recent hires will require further follow-up of the cohort. Subsequent to these studies, all seven plants have closed. The Maryland plant, which closed in the mid-1980s, was the last of these plants to close. Two new facilities have opened in North Carolina and Texas. A mortality study has recently been completed of workers at the plant in North Carolina [Pastides et al., 1994].

The Public Health Service concluded its report in 1953 by stating, "It is recommended that all employees who have worked 5 years or more in the chromate industry should be X-rayed every 3 months, and their films should be read by a competent roentgenologist. The study of the morbidity and mortality experience of workers in chromate plants should be continued. The local health department should follow-up chromate workers who have worked in the industry 5 years or more." No such follow-up was instituted for the plants in New Jersey until our project was initiated. In 1990–1991, we conducted a high risk notification program [Rosenman et al., 1993] and a mortality study of workers from the four original New Jersey plants. This paper presents the results of the mortality study. We were specifically concerned about whether there was a continued risk of death from lung cancer and whether there was an increased risk of mortality from kidney, nasal, and/or stomach cancer. There are some suggestive data in the literature for an increased risk for these latter three types of cancer [Langard, 1990].

METHODS

The cohort was compiled from Social Security Administration "941" forms that are submitted by corporations on a quarterly basis. These forms contain a worker's name, social security number, and the employer's quarterly contribution on that worker to social security. Quarterly social security records for the following dates were obtained: Plant A, 1951 until its closure in 1954; plant B, 1951 until its closure in 1971; plant C, 1937 until its closure in 1964; and plant D, 1937 until its closure in 1954. The only activity at plants A–D was the production of chromium products. The quarterly records were used to determine the duration of employment.

The following sequential steps were taken to trace individuals (next of kin of deceased individuals were not contacted and living individuals did not receive a second contact if they responded to a previous contact): (1) identification of deceased individuals from social security and other governmental records provided to outside commercial firms; (2) a mailing by the Internal Revenue Service (IRS); (3) identification of additional dead individuals from New Jersey death tapes maintained by the New Jersey Department of Health; (4) a mailing to individuals who filed New Jersey income tax forms; (5) a second mailing by the Internal Revenue Service; (6) identification of addresses by the Social Security Administration of individuals or dependents receiving benefits; (7) New Jersey motor vehicles records; and (8) the National Death Index. A more detailed description of the methods to assemble the cohort and notify members of the cohort has already been published [Rosenman et al., 1993]. Death certificates were coded by trained nosologists. For the majority of deaths we used the cause of death codes assigned by the New Jersey Department of Health Vital Statistics' personnel. All causes of death were converted to the 9th International Classification of Diseases.

Proportionate mortality ratios (PMR) and proportionate cancer mortality ratios (PCMR) were calculated for the three companies (one company owned two facilities, facilities A and B) together as well as individually. We used the O/E system, Version 3.5 developed by the National Cancer Institute to perform the mortality analysis and calculate the 95% confidence limits. Analyses were done evaluating duration of work, latency from first employment, and time since cessation of work. Duration and time of hire were based on quarters reported by social security. For facilities A and B, we only had one quarter's report for each year, and we assumed the individual worked the whole year that a quarter was reported. For individuals in the other two companies who reached their social security wage limit and would only have three quarters in a year but the years before

TABLE I. Vital Status of Cohort of Chromium Smelter Workers, New Jersey 1991

	Dead				Live				Unknown			
	Ever employed		Employed >1 year		Ever employed		Employed >1 year		Ever employed		Employed >1 year	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Facilities A & B	303	(42.7)	229	(51.8)	334	(47.0)	196	(44.1)	73	(10.3)	19	(4.3)
Facility C	473	(55.8)	312	(66.8)	278	(32.8)	142	(30.4)	97	(11.4)	13	(2.8)
Facility D	1108	(58.6)	491	(76.8)	444	(23.5)	126	(19.7)	339	(17.9)	21	(3.3)
Overall	1858[a]	(54.5)	1014[b]	(66.5)	1044[c]	(30.6)	458[d]	(30.0)	506[e]	(14.8)	53	(3.5)

[a]Twenty-six had worked at more than one facility and are included only once in the total.
[b]Eighteen had worked at more than one facility and are included only once in the total.
[c]Twelve had worked at more than one facility and are included only once in the total.
[d]Six had worked at more than one facility and are included only once in the total.
[e]Three had worked at more than one facility and are included only once in the total.

and after that year showed the individual working, we assumed the person had worked the full year.

We performed all analyses using U.S. general population deaths to generate the expected mortality events. All PMRs were adjusted by 5 year age and 5 year time period of death categories. Analyses were gender and race specific. Given the small number of women, only overall proportionate mortality ratios were performed for white women. There were two deaths among black women. This is an insufficient number of deaths for analysis. Death certificates from eight men were not included in the analysis because no information on race was available.

RESULTS

There were 3,408 individuals identified who had worked at facilities A–D. Facilities A and B had 710 workers; facility C had 848, and facility D had 1,891. Forty-one individuals had worked at more than one facility. The vital status of the cohort is shown in Table I. Approximately half had died. Thirty-one percent were presumed to be alive. Fifteen percent neither completed a questionnaire nor were noted to have a current address by either the Social Security Administration (SSA) nor the New Jersey Department of Taxation (NJDT). The United States Internal Revenue Service would not inform us if an individual had a current address. If no questionnaire was completed and no address was provided by SSA or NJDT, the person was considered lost to follow-up. Among those who had worked more than 1 year, approximately 67% had died, 30% had completed a questionnaire, and only 4% had neither completed a questionnaire nor were known to have a current address.

A higher percentage of workers from facilities A and B were known to be alive. The percentage lost to follow-up from all of the facilities decreased among the workers with more than 1 year of work (10–18% vs. 3–4%). Of the 1,858 individuals who were known to have died, death certificates were located on approximately 94%. There was no difference in our ability to find death certificates on the longer duration vs. short duration employees (93.6% vs. 93.9%).

The PMRs for white and black men are shown in Table II. For white men there were 1,279 deaths. There was a statistical increase for death from all cancer, digestive cancer, stomach cancer, nasal cavity/sinus cancer, and lung cancer. There is a statistically significant decrease for death for tuberculosis, prostate cancer, vascular lesions of the central nervous system, and all external causes of death, including motor vehicle accidents and suicide (Table II). For black men there were 394 deaths. There was a statistically significant increase for death for all cancer, lung cancer, bladder cancer, and diseases of the digestive system. There were no statistically significant decreases (Table II).

The PCMRs are shown for white and black men in Table II. For white men there were 170 deaths from lung cancer. The PCMR was 1.51; 95% confidence limit (CL) was 1.29–1.75. For nasal cavity/sinus cancer, the PCMR was 5.18 (2.18–11.30) (Table II). For black men there were 54 deaths from lung cancer, eight deaths from bladder cancer, and no deaths from nasal cavity/sinus cancer. The PCMR for lung cancer was 1.34; the 95% CL was 1.00–1.75. The PCMR for bladder cancer was 3.30; the 95% CL was 1.42–6.51 (Table II).

For white women there were 56 deaths. There was a statistically significant increase for death only from chronic rheumatic heart disease (Table III). The PMRs and PCMRs for white and black men for selected cancers by duration of employment are shown in Tables IV and V. For all malignant neoplasms and lung cancer, the PMR is statistically increased in the deaths of white men who worked 2–10, 11–20, and >20 years (Table IV). Deaths from prostate cancer are statistically decreased for those who worked ≤1 year. For the PCMR analysis, lung cancer remained statis-

TABLE II. Study of Former Chromium Smelter Workers in New Jersey: Proportionate Mortality and Proportionate Cancer Mortality Ratios for White and Black Men

	White men			Black men		
Disease	**Obs**	**PMR/CL**	**PCMR/CL**	**Obs**	**PMR/CL**	**PCMR/CL**
Tuberculosis	3	.30[a]	—	5	.89	—
		(.06–.88)	—		(.92–2.07)	—
All malignant neoplasms	371	1.37[a]	—	125	1.43[a]	—
		(1.23–1.51)	—		(1.19–1.70)	—
Digestive	103	1.33[a]	.91	27	1.03	.70
		(1.08–1.61)	(.75–1.11)		(.68–1.50)	(.46–1.02)
Esophagus	9	1.38	.99	6	1.14	.80
		(.63–2.62)	(.45–1.88)		(.42–2.49)	(.29–1.74)
Stomach	30	2.05[a]	1.24	4	.68	.44
		(1.38–2.92)	(.84–1.77)		(.18–1.74)	(.12–1.11)
Colo/rectal	40	1.17	.83	8	1.06	.74
		(.86–1.59)	(.61–1.13)		(.54–2.09)	(.37–1.46)
Liver	9	1.61	1.04	2	.95	.62
		(.73–3.05)	(.48–1.98)		(.11–3.43)	(.07–2.23)
Nasal cavity/sinus	6	6.85[a]	5.18[a]	0	—	—
		(3.14–14.94)	(2.37–11.30)		—	—
Lung	170	1.95[a]	1.51[a]	54	1.88[a]	1.34
		(1.67–2.27)	(1.29–1.75)		(1.41–2.45)	(1.00–1.75)
Prostate	13	.57[a]	.44[a]	15	1.49	1.09
		(.30–.98)	(.23–.75)		(.83–2.45)	(.61–1.80)
Bladder	6	.69	.50	8	4.96[a]	3.30[a]
		(.25–1.51)	(.18–1.09)		(2.13–9.76)	(1.42–6.51)
Kidney	4	.61	.45	3	2.22	1.55
		(.17–1.57)	(.12–1.14)		(.45–6.50)	(.31–4.54)
Atherosclerotic heart disease	445	.97	—	85	.90	—
		(.88–1.07)	—		(.72–1.11)	—
Vascular lessions of CNS	71	.78[a]	—	24	.68	—
		(.61–.98)	—		(.44–1.01)	—
Respiratory disease	89	1.01	—	24	1.00	—
		(.81–1.24)	—		(.64–1.49)	—
Diseases of genito urinary system	15	.71	—	5	.47	—
		(.40–1.17)	—		(.15–1.11)	—
External causes	44	.56	—	25	.76	—
		(.41–.75)	—		(.49–1.12)	—

[a]$p < .05$.
Obs, observed; CL, confidence limits; PMR, proportionate mortality ratio; PCMR, proportionate cancer mortality ratio.

tically increased for white men who worked 2–10, 11–20, and >20 years. Death from prostate cancer remained reduced in those working 1 year or less (Table IV). Nasal cavity/sinus cancer was increased in all duration categories.

For black men there are statistically increased PMRs for death from all malignant neoplasms for duration of employment from 2 through 10 years and 11 through 20 years; for lung cancer for work in all duration year groups except 1 year or less; and for bladder cancer for duration of work 1 year or less (Table V). For the PCMRs, statistical in-

TABLE III. Study of Former Chromium Smelter Workers in New Jersey: Proportionate Mortality and Proportionate Cancer Mortality Ratios for White Women

	Obs	PMR	CL	PCMR	CL
All malignant neoplasms	9	.64	(.29–1.22)	—	—
Digestive cancer	4	1.09	(.29–2.78)	1.70	(.46–4.35)
Lung cancer	1	.45	(.01–2.51)	.79	(.01–4.26)
Breast cancer	2	.73	(.08–2.63)	1.04	(.12–3.77)
Atherosclerotic heart disease	20	1.19	(.73–1.83)	—	—
Rheumatic heart disease	3	5.94[a]	(1.19–17.35)	—	—
Respiratory disease	4	1.16	(.31–2.98)	—	—
External causes	1	.53	(.01–2.96)	—	—

[a]$p < .05$.
Obs, observed; PMR, proportionate mortality ratio; CL, confidence limits; PCMR, proportionate cancer mortality ratio.

creases were found for lung cancer deaths for deaths among black men with >20 years duration of work and for bladder cancer for deaths ≤1 year duration of work (Table V).

The PMRs and PCMRs for time from first employed by duration of employment for lung cancer in black and white men are shown in Table VI. For white men, there were statistically significant increased PMRs and PCMRs for death from lung cancer for all latency periods. Generally for durations greater than 1 year, both PMRs and PCMRs were statistically increased. For black men, there was a statistically significant increased PMR for death from lung cancer for duration of work ≤1 year and 11–20 years from first hire, duration of work 11–20 years with a similar latency period, and duration >20 years with a similar latency period. The same time periods, except <1 year duration of work, showed statistically increased PCMRs.

Lung cancer PMRs and PCMRs were also analyzed for duration of employment by time since last worked (Table VII). For white men, the PMRs for lung cancer were statistically increased for all time periods since last worked. For black men, the PMRs for death from lung cancer were statistically increased for ≤10 years since last worked and for 11–20 years since last worked. For the PCMR, only death for lung cancer within 0–10 years since last worked was statistically significant.

The statistically significant increase in bladder cancer PMR and PCMR for black workers was seen among those who worked 1 year or less, >20 years after first hire at facility D. Seven of the eight deaths from bladder cancer were among facility D employees. Five had worked between 1944 and 1947. The other two individuals had worked in 1951. The eighth death of a black worker from bladder cancer was from facility C. He developed his cancer more than 20 years after hire after having worked for 22 years, from 1939 to 1961. The PMR and PCMRs for bladder cancer for this one death from facility C were also elevated but not statistically significant. Bladder cancer among white men was not elevated. There were five deaths from bladder cancer among white men. Four occurred 20 years after first hire and 1, 0–10 years after first hire. Of the white men who died of bladder cancer, two had worked for 1 year or less, one for 2–10 years, one for 11–20 years, and one for >20 years. Two had occurred among workers from facility A/B, one from facility C, and two from facility D. Both of the two deaths among white men from bladder cancer at facility D were among workers who had worked less than 1 year in 1945 or 1948. One occurred >20 years and the other <10 years after first hire.

No nasal cavity/sinus cancers occurred among black men. An increase in the PMRs and PCMRs for white men was seen in all duration of work categories >1 year (Table IV). Table VIII shows the PMRs and PCMRs for latency from first worked and last worked. Two of the cancers occurred in facilities A and B, three in facility C, and one in facility D. The PMRs and PCMRs were 11.63 (3.19–42.40) and 8.00 (2.19–29.17) for facility A and B; 11.86 (4.03–34.87) and 9.01 (3.06–26.49) for facility C, and 2.15 (.38–12.16) and 1.67 (.29–9.47) for facility D. The specific type of cancers were nasal cavities (2); maxillary sinus (2), nasal cavity/middle ear and accessory site, undetermined (1); and accessory sinus, not specified (1). Of the eight deaths not included in the analysis because information on race was not available, one person from facility A/B died of laryngeal cancer and one person from facility D died of cancer of the digestive organs, unspecified.

DISCUSSION

The mortality experience of workers from the four facilities owned by three companies that we studied have been previously studied [Machle and Gregorius, 1948; Public Health Service, 1953]. Machle in 1948 found that 17–27% of deaths from 1930 to 1947 in these four facilities were secondary to lung cancer; this was a 16-fold increase. He did not include workers who left the facility. The Public Health Service included three facilities in addition to the ones we studied. They found a 29-fold increase in lung cancer during the 1940s. This risk was 14-fold among white workers and 80-fold for black workers. A small percentage of the lung cancer deaths in our study occurred during the time period studied by either Machle or the Public Health Service. Only 5.9% of all deaths and 9.4% of lung cancer deaths among white men, and 3.6% of all deaths and 7.4% of lung cancer deaths among black men, in our study occurred before 1950.

Lung cancer was the cause of 12.9% of the deaths in

TABLE IV. Study of Former Chromium Smelter Workers in New Jersey: Proportionate Mortality and Proportionate Cancer Mortality Ratios for White Men for Selected Cancers by Duration of Work

	Duration (years)											
	<1 year			>1–10 years			>10–20 years			>20 years		
Type of cancer	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL
All malignant neoplasms	131	1.09 (.91–1.29)	— —	129	1.59[a] (1.34–1.87)	— —	62	1.63[a] (1.25–2.09)	— —	31	1.51[a] (1.03–2.15)	— —
Digestive	43	1.34 (.97–1.80)	1.24 (.90–1.67)	40	1.44[a] (1.03–1.96)	.82 (.59–1.12)	17	1.45 (.84–2.32)	.84 (.49–1.34)	3	.51 (.10–1.49)	.32 (.07–.95)
Esophagus	3	1.04 (.21–3.04)	.97 (.19–2.82)	3	1.33 (.27–3.90)	.80 (.16–2.33)	3	3.28 (.66–9.58)	2.00 (.40–5.84)	0	— —	— —
Stomach	11	2.08 (1.04–3.73)	1.95 (.97–3.48)	14	2.39[a] (1.31–4.02)	1.17 (.64–1.96)	3	1.22 (.25–3.56)	.64 (.13–1.87)	2	1.87 (.21–6.76)	1.08 (.12–3.91)
Colo/rectal	19	1.31 (.84–2.05)	1.21 (.77–1.89)	15	1.25 (.76–2.06)	.76 (.46–1.25)	6	1.18 (.25–2.57)	.70 (.32–1.53)	0	— —	— —
Liver	4	1.84 (.50–4.71)	1.71 (.46–4.37)	2	.95 (.11–3.43)	.50 (.06–1.80)	2	2.23 (25–8.05)	1.25 (.14–4.52)	1	2.36 (.03–13.15)	1.47 (.02–8.19)
Nasal cavity/ sinus	0	— —	— —	2	6.87[a] (1.88–25.06)	4.88[a] (1.34–17.79)	3	23.62[a] (8.03–69.50)	14.29[a] (4.86–42.01)	1	15.38[a] (2.71–87.16)	9.26[a] (1.63–52.45)
Lung	55	1.33 (1.00–1.73)	1.22 (.92–1.59)	67	2.37[a] (1.84–3.01)	1.60[a] (1.24–2.03)	30	2.70[a] (1.82–3.85)	1.82[a] (1.23–2.60)	18	2.83[a] (1.68–4.47)	1.94[a] (1.15–3.06)
Prostate	2	.21[a] (.02–.76)	.19[a] (.02–.70)	10	1.32 (.63–2.42)	.95 (.46–1.76)	0	— —	— —	1	.47 (.01–2.62)	.34 (.00–1.91)
Bladder	2	.57 (.06–2.06)	.53 (.06–1.92)	1	.67 (.07–2.41)	.42 (.05–1.51)	1	.72 (.01–4.01)	.42 (.01–2.34)	1	1.36 (.02–7.55)	.90 (.01–5.02)
Kidney	1	.34 (.00–1.90)	.32 (.00–1.76)	2	.90 (.10–3.23)	.55 (.06–1.99)	1	1.14 (.01–6.32)	.70 (.01–3.87)	0	— —	— —

[a] $p < .05$.
See Table II for abbreviations.

our study. We found a 1.95 (CL 1.67–2.27) risk for lung cancer among white male workers and 1.88 (CL 1.41–2.45) for black male workers (Table II). Given the limitations of a PMR analysis, a more valid estimate of the risk is probably the PCMR. This showed a risk of lung cancer for white male workers of 1.51 (CL 1.29–1.75) and 1.34 (CL 1.00–1.75) for black male workers (Table II). The risk increased with the number of years worked. The PCMR for lung cancer for white men increased from 1.22 (CL .92–1.59) to 1.60 (CL 1.24–2.03), to 1.82 (CL 1.23–2.60), to 1.94 (CL 1.15–3.06) with increasing years worked (Table IV). For black men the PCMRs for lung cancer increased from .99 (CL .54–1.57) to 1.30 (CL .78–2.04), to 1.93 (CL .96–3.45), to 3.08 (CL 1.13–6.71) for increasing duration of employment (Table IV). We did not find the striking difference in risk of lung cancer among white and black workers previously reported [Public Health Service, 1953].

No excess of lung cancer was found in women. This is not unexpected as women were likely to have had office jobs and not have been directly involved with production. There is no evidence from our data that after the first 10 years after leaving employment there is any decrease in the risk of lung cancer with time elapsed from last exposure (Table VII). The risk is still elevated for white men more than 20 years after last exposure but was not increased for black men more than 20 years after last exposure.

We were not able to separate out exposure to hexavalent vs. trivalent chromium nor examine risk by exposure estimates. Previous industrial hygiene studies of these facilities have shown exposure to chromium of both valences throughout the plant, with 8–62% of the air samples for hexavalent chromium above the American Conference of Governmental Industrial Hygienists recommended threshold limit value of .05 mg/m^3 [Public Health Service, 1953].

We found an increase in nasal cavity/sinus cancer among white workers. The increased risk was found in both short and long duration workers (Table V). It occurred within the first 20 years after leaving employment. The risk

TABLE V. Study of Former Chromium Smelter Workers in New Jersey: Proportionate Mortality and Proportionate Cancer Mortality Ratios for Black Men for Selected Cancers by Duration of Work

	Duration (years)											
	≤1 years			>1–10 years			>10–20 years			>20 years		
Type of cancer	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL
All malignant neoplasms	53	1.16	—	46	1.52[a]	—	19	2.35[a]	—	7	2.11	—
		(.87–1.51)	—		(1.11–2.02)	—		(1.41–3.67)	—		(.84–4.34)	—
Digestive	12	.91	.79	11	1.19	.76	14	1.55	.61	0	—	—
		(.47–1.58)	(.41–1.37)		(.59–2.13)	(.38–1.37)		(.42–3.97)	(.16–1.56)	—	—	
Esophagus	2	.73	.67	4	2.21	1.43	0	—	—	0	—	—
		(.08–2.63)	(.08–2.41)		(.59–5.65)	(.38–3.66)		—	—		—	—
Stomach	2	.72	.64	2	.92	.56	0	—	—	0	—	—
		(.08–2.61)	(.07–2.30)		(.10–3.33)	(.06–2.01)		—	—		—	—
Colo/rectal	5	1.28	1.08	1	.38	.25	2	2.77	1.21	0	—	—
		(.55–3.00)	(.46–2.53)		(.07–2.15)	(.04–1.42)		(.76–10.10)	(.33–4.41)		—	—
Liver	0	—	—	1	1.31	.81	1	4.62	1.66	0	—	—
		—	—		(.02–7.31)	(.01–4.52)		(.06–25.69	(.02–9.22)		—	—
Lung	18	1.15	.99	19	1.96[a]	1.30	11	4.50[a]	1.93	6	6.30[a]	3.08[a]
		(.68–1.81)	(.59–1.57)		(1.18–3.07)	(.78–2.04)		(2.24–8.05)	(.96–3.45)		(2.30–13.71)	(1.13–6.71)
Prostate	8	1.55	1.25	4	1.13	.82	3	2.96	1.49	0	—	—
		(.67–3.06)	(.54–2.46)		(.30–2.89)	(.22–2.11)		(.60–8.65)	(.30–4.35)		—	—
Bladder	7	8.91[a]	7.39[a]	1	1.71	1.08	0	—	—	0	—	—
		(3.57–18.35)	(2.96–15.22)		(.02–9.49)	(.01–6.00)		—	—		—	—
Kidney	1	1.41	1.24	2	4.28	2.81	0	—	—	0	—	—
		(.02–7.85)	(.02–6.92)		(.48–15.45)	(.32–10.16		—	—		—	—

[a]$p < .05$
See Table II for abbreviations.

appeared greater among workers from facilities A, B, and C. There have been small numbers of nasal cavity/sinus cancers reported in other studies and case reports of nasal cavity/sinus cancers among chromium-exposed workers [Langard, 1990; Satoh et al., 1994].

A cluster of bladder cancer among black men who worked for 1 year or less at facility D in the 1940s and early 1950s was found. No known bladder carcinogens are mentioned in the industrial hygiene discussion from historical reports [Public Health Service, 1953]. The bladder cancers are occurring more than 20 years after the start of employment. The last death from bladder cancer occurred in 1990.

Although the PMR for stomach cancer was increased among white men (Table II), the risk did not increase with years worked (Table IV). There was no suggestion of increased kidney cancer in white men. There was a nonstatistically significant increase in black men (Table II). There have been limited data in previous studies suggesting a possibility of an increased risk for these two types of cancer [Langard, 1990].

Limitations of our mortality analysis include the fact that 10.9% of all workers could not be traced and 8.4% of workers with more than 1 year of work experience could not be traced. Because we used data systems that were likely to identify if someone were alive (Internal Revenue Service; federal and state records, and Social Security Administration records of those receiving benefits) or died in the last 10–30 years (National Death Index, New Jersey Vital Statistics, and Social Security records), we suspect that many of the individuals not traced died prior to the availability of computerized records of death. This would not bias the current risk of lung cancer in this cohort but might cause us to underestimate the historical risk. Another limitation is that we depended on social security records to define our cohort. For facilities A and B we had no records before 1951. For facility C, we had no records before 1937. For facility D we had limited personnel records before 1937, but our main data source was social security records, which began in 1937. One hundred-and-fifty-eight (5.8%) of our cohort from facilities C and D were working in 1937, and 133 (18.7%) of the cohort from facility A/B in 1951. We do not know how long before 1937 or 1951, respectively, they

TABLE VI. Study of Former Chromium Smelter Workers in New Jersey: Proportionate Mortality and Proportionate Cancer Mortality Ratios for White and Black Men for Lung Cancer by Duration of Employment and Time Since First Employed

	Time since first employed (years)								
	0–10			>10–20			>20		
Duration (years)	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL
White men									
≤1	3	2.89	1.99	5	1.08	1.28	47	1.32	1.19
		(.58–8.44)	(.40–5.82)		(.39–2.53)	(.41–2.99)		(.97–1.75)	(.87–1.58)
>1–10	19	5.05[a]	1.93[a]	12	2.44[a]	1.82	36	1.84[a]	1.42[a]
		(3.04–7.89)	(1.16–3.01)		(1.26–4.26)	(.94–3.18)		(1.29–2.55)	(.99–1.96)
>10–20	0	—	—	18	4.72[a]	2.39[a]	12	1.66	1.34
		—	—		(2.80–7.47)	(1.42–3.78)		(.86–2.89)	(.69–2.35)
>20	0	—	—	0	—	—	18	2.83[a]	1.94[a]
		—	—		—	—		(1.68–4.47)	(1.15–3.06)
All	22	4.52[a]	1.94[a]	35	2.62[a]	1.94[a]	113	1.64[a]	1.36[a]
		(2.83–6.85)	(1.21–2.93)		(1.83–3.65)	(1.35–2.70)		(1.35–1.97)	(1.12–1.63)
Black men									
≤1	0	—	—	4	4.05[a]	2.75	14	.96	.84
		—	—		(1.09–10.36)	(.74–7.03)		(.53–1.61)	(.46–1.41)
>1–10	2	5.38	3.09	3	2.46	1.65	14	1.73	1.16
		(.60–19.42)	(.35–10.22)		(.50–7.20)	(.33–4.83)		(.95–2.91)	(.63–1.92)
>10–20	0	—	—	6	11.61[a]	4.11[a]	5	2.59	1.18
		—	—		(4.24–25.27)	(1.50–8.96)		(.84–6.05)	(.38–2.75)
>20	0	—	—	0	—	—	6	6.30[a]	3.08[a]
		—	—		—	—		(2.30–13.71)	(1.13–6.71)
All	2	3.86	3.09	13	4.77[a]	2.75[a]	39	1.53[a]	1.11
		(.43–13.93)	(.35–11.14)		(2.54–8.16)	(1.46–4.70)		(1.09–2.09)	(.79–1.52)

[a]$p < .05$.
See Table II for abbreviations.

were working. This lack of information about work before 1937 or 1951 would cause us to overestimate the risk for shorter duration work and shorter latency from first hire. However, for the time periods where records were available, the use of social security records ensures that we had complete ascertainment of the total workforce for all but temporary or contract employers.

We could not distinguish between production workers and management. Management personnel presumably had lower exposures and their inclusion would cause us to underestimate the risk of lung cancer. We did not have access to information about cigarette smoking among deceased workers. We know from historical data that 81.1% of chromate workers smoked tobacco products previous to 1950. This percentage is similar to blue collar worker population percentages from this time period [Haenzel et al., 1956]. Seventy percent of living workers who responded to the questionnaire had ever smoked cigarettes, although only 16–30.2% continued to smoke. Overall, there was no increase in other smoking-related diseases. For white men, the PMR for emphysema was 1.13 (CL .68–1.76) and for black men the PMR was .42 (CL .01–2.35). For laryngeal cancer, the PCMR was .90 (CL .29–2.10) for white men and .45 (CL .01–2.49) for black men. For atherosclerotic heart disease, the PMR was 0.97 (CL .88–1.07) for white men and 0.90 (CL .72–1.11) for black men. There was an increase in bladder cancer in black men, but this was specific to a cluster of disease in one facility. Only by continued follow-up of the 790 individuals on whom we have smoking data can we address the issue of interaction between smoking and chromium exposure.

Because of deficits in heart disease in our cohort and the known phenomenon that the healthy worker effect will cause the PMR to be an overestimate of the true risk, we calculated PCMRs throughout our analysis. The PCMR is less biased by the healthy worker effect and would be a better predictor of the true risk. We did not draw any conclusions not supported by the PCMR analysis.

As we categorized our study group by race, facility, duration, and latency, our sample size became smaller. Be-

TABLE VII. Study of Former Chromium Smelter Workers in New Jersey: Proportionate Mortality and Proportionate Cancer Mortality Ratios for White and Black Men for Lung Cancer by Duration of Employment and Time Since Last Employed

	Time Since Last Employed (years)								
	0–10			>10–20			>20		
Duration (years)	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL
White men									
≤1	3	2.77	1.70	5	1.05	1.37	47	1.32	1.19
		(.56–8.11)	(.34–4.98)		(.34–2.44)	(.44–3.20)		(.97–1.76)	(.87–1.58)
>1–10	26	4.57[a]	1.96[a]	10	1.68	1.41	31	1.87[a]	1.42
		(2.99–6.70)	(1.28–2.88)		(.80–3.09)	(.68–2.59)		(1.27–2.65)	(.96–2.01)
>10–20	21	3.87[a]	2.12[a]	7	1.89	1.40	2	1.01	1.28
		(2.39–5.92)	(1.31–3.24)		(.76–3.89)	(.56–2.89)		(.11–3.64)	(.14–4.62)
>20	11	4.09[a]	2.50[a]	4	1.68	1.10	3	2.32	2.40
		(2.04–7.32)	(1.24–4.47)		(.45–4.31)	(.30–2.81)		(.47–6.77)	(.48–7.01)
All	61	4.10[a]	2.08[a]	26	1.55[a]	1.37	83	1.50[a]	1.29[a]
		(3.14–5.27)	(1.59–2.67)		(1.01–2.26)	(.90–2.01)		(1.19–1.86)	(1.03–1.60)
Black men									
≤1	0	—	—	4	3.78[a]	2.75	14	.97	.84
		—	—		(1.02–9.67)	(.74–7.03)		(.53–1.62)	(.46–1.41)
>1–10	4	4.72[a]	2.37	4	1.82	1.51	11	1.66	1.07
		(1.27–12.09)	(.64–6.08)		(.49–4.66)	(.41–3.86)		(.83–2.97)	(.54–1.92)
>10–20	8	10.16[a]	3.58[a]	2	2.45	.91	1	1.19	.78
		(4.38–20.03)	(1.54–7.06)		(.28–8.85)	(.10–3.29)		(.02–6.61)	(.01–4.35)
>20	4	7.54[a]	3.48	2	5.76	2.51	0	—	—
		(2.03–19.31)	(.94–8.91)		(.65–20.80)	(.28–9.05)		—	—
All	16	6.88[a]	2.88[a]	12	2.72[a]	1.69	26	1.18	.92
		(3.93–11.18)	(1.80–5.13)		(1.40–4.74)	(.87–2.95)		(.77–1.73)	(.60–1.35)

[a]$p < .05$.
See Table II for abbreviations.

TABLE VIII. Study of Former Chromium Smelter Workers in New Jersey: Proportionate Mortality and Proportionate Cancer Mortality Ratios for White Men for Nasal Cavity/Sinus Cancer by Time Since First Employed and Time Since Last Employed

	Time (years)								
	0–10			>10–20			>20		
	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL	Obs	PMR/CL	PCMR/CL
Time from first employed									
Nasal cavity/sinus	2	28.99[a]	15.5[a]	1	5.32	3.75	3	4.85	3.93[a]
		(7.95–105.70)	(4.25–56.54)		(.94–30.13)	(.66–21.22)		(1.65–14.25)	(1.34–11.56)
Time from last employed									
Nasal cavity/sinus	5	24.27[a]	12.79[a]	1	5.24	4.55	0	—	—
		(10.37–56.82)	(5.46–29.94)		(.92–29.60)	(.80–25.75)		—	—

[a]$p < .05$.
See Table II for abbreviations.

cause of this we had insufficient statistical power in many of these subgroups to show a statistically elevated risks. However, the trends with duration and latency are supportive of the causal relationship between work in these facilities and the development of lung cancer and nasal cavity/sinus cancer.

In summary, we found significant increases in lung and nasal cavity/sinus cancers. Overall risks of lung cancer were greater for white vs. black men, although in the long duration and long latency since first employed categories the risk of lung cancer among black men was greater. Increased nasal cavity/sinus cancer was only seen in white men. An increase in bladder cancer was seen in one facility among short-duration black workers. The risk of lung cancer remains elevated more than 20 years after workplace chromium exposure has ceased. Survivors of this cohort would potentially benefit from the development of tests for the early detection of lung cancer.

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