Exhibit 271

Cancer Mortality Among Aircraft Manufacturing Workers

An Extended Follow-Up

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Objective: Extended cancer follow-up among 77,943 aircraft workers. **Methods:** Comprehensive exposure information enabled detailed classification of trichloroethylene (TCE), perchloroethylene (PCE), mixed solvents, and chromates exposure among these workers. **Results:** Exposure to TCE, PCE, mixed solvents or chromates was not associated with increased cancer risk overall or for most cancer sites. Elevated rates compared with the general population were seen for non-Hodgkin lymphoma for PCE exposure, and colon and testicular cancers and multiple myeloma for mixed solvents exposure. Internal cohort analyses, however, showed no significant trends of increasing risk for these cancers with increasing years of exposure to TCE, PCE or mixed solvents. **Conclusion:** This large, long-term cohort study with comprehensive exposure assessment found no consistent evidence of increased cancer risk overall or by site among aircraft workers, including those with long-term exposure to TCE, PCE, and mixed solvents.

We previously conducted a large-scale epidemiologic mortality study of workers at the Lockheed Martin aircraft manufacturing facilities in Burbank, California to assess the risk of cancer.[1] Many of the workers had regular exposure to known or suspected human carcinogens, including chromates, trichloroethylene (TCE), perchloroethylene (PCE), and other solvents, providing one of the largest occupational cohorts in which to evaluate the health effects associated with these compounds. A comprehensive exposure assessment was also performed.[2] During the initial follow-up period, January 1960 through December 1996, 20,236 deaths were identified, and the cohort of aircraft workers experienced moderately low overall mortality (standardized mortality ratio [SMR] = 0.83) and overall and site-specific cancer mortality close to expectation.[1]

Because of the scientific informativeness of large occupational cohort studies with documented long-term exposure to known or suspected human carcinogens, and their increasing rarity in the literature, we extended our follow-up by another 12 years, through 2008. In addition, using more extensive tracing methods unavailable at the time of the initial study, we were able to identify an additional 254 deaths among cohort members who died before 1996 and to confirm alive status for virtually all workers not reported to have died by the end of the present follow-up.

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METHODS

The study was reviewed and approved by the Westat Institutional Review Board (project #9927).

Cohort Definition

Details of cohort definition and exposure assessment have been described previously.[1,2] In brief, the original study population comprised 77,965 workers employed on or after January 1, 1960 for at least 1 year at the Lockheed Martin aircraft manufacturing facilities in Burbank, California. Workers were identified using three overlapping sources, employee work history (Kardex) cards, personnel files, and retirement records, which together provided complete job histories, including dates of employment and occupational titles, job codes, departments, and plants. Using enhanced probabilistic matching software, we identified and removed 22 duplicate data entries, so that the final study cohort comprised 77,943 workers.

Determination of Vital Status

In the original follow-up, vital status was sought for all workers through December 31, 1996, and 20,236 deaths were identified. For the current follow-up, deaths through December 31, 2008 were identified by linkage with the California Death Statistical Master File, National Death Index (NDI), Social Security Administration's (SSA) Death Master File, and Comserv, Inc, a computer services firm specializing in locating death records (www.comserv-inc.com), as well as Lockheed Martin pension and other records. Cohort members were matched against these registers using social security number, name, date of birth, and sex to identify those who died and to obtain date and cause of death. For matching with the SSA Death Master File and the California Death Statistical Master File, we used the Centers for Disease Control and Prevention program LinkPlus, which incorporates a probabilistic scoring system and does not require exact matches on all variables.[3] All questionable matches that were not exact were individually reviewed.

A total of 34,298 (44%) workers in the study cohort were found to have died by December 31, 2008. Using SSA's Service to Epidemiologic Researchers (http://www.ssa.gov/policy/about/epidemiology.html) and LexisNexis records of last known residential address, tracing methods that were unavailable at the time of the initial follow-up of this cohort, we were able to confirm that 42,309 workers not identified as having died were, in fact, alive as of December 31, 2008. For the remaining 1336 workers (1.7% of the workers), vital status as of December 31, 2008 was unknown (Table 1).

Underlying cause of death was sought from the California Death Statistical Master File for those dying in California, and from the NDI for non-California residents dying in 1979 through 2008. For all other deaths, death certificates were requested from state vital statistics departments or from Lockheed Martin records. Death certificates for a small percentage of workers who died after 1978 also had to be requested because the death files in NDI are not entirely complete in the start-up years.[4] A trained nosologist

TABLE 1. Vital Status and Selected Occupational Characteristics of 77,943 Lockheed Martin Aircraft Manufacturing Workers Employed 1960–1996 for at Least 1 Year and Followed Through 2008

	Factory $N = 45,318$		Non-Factory* $N = 32,625$		Total $N = 77,943$	
Characteristic	***N***	**%**	***N***	**%**	***N***	**%**
Vital status (Dec 31, 2008)						
Dead	22,708	50.1	11,590	35.5	34,298	44.0
Alive	21,814	48.1	20,495	62.8	42,309	54.3
Unknown	796	1.8	540	1.7	1,336	1.7
Selected exposures						
Chromates†	7,458	16.5				
Trichloroethylene	5,443	12.0				
Perchloroethylene	5,830	12.9				
Mixed solvents	32,735	72.2				

*Office, technical, administrative, scientific, and engineering person.
†Correction of a minor coding error resulted in the identification of 15 additional workers with intermittent chromates exposure.

coded causes of death from the death certificates according to the International Classification of Disease revision in use at the time the death occurred.

Exposure Assessment

The Burbank facilities consisted of four major plants, over 200 buildings, and a changing workforce over 60 years of operation that approached 30,000 employees annually during peak years. Routine exposure to chromate-containing compounds occurred primarily while operating process equipment tank lines used for plating or corrosion protection of metals, or when using chromate-based primers or paints. Trichloroethylene was the primary organic solvent used in vapor degreasers until 1966, when it was replaced by PCE due to California air pollution control measures. In addition to TCE and PCE, a wide variety of solvents were used, including methyl ethyl ketone, alcohols, petroleum distillates, 1,1,1-trichloroethane, methylene chloride, methyl isobutyl ketone, acetone, toluene, xylene, and various freons. Due to the large variety of solvents used and the changing pattern of use throughout the years, an exposure classification was created called mixed solvent exposures.

Our study cohort of 77,943 workers included 32,625 workers employed in non-factory positions, such as administration, office and technology, and science and engineering. All non-factory employees were assigned "no chemical usage" and removed from further consideration in the assessment of job titles and chemical exposures. A detailed description of the assessment of chromates, TCE, PCE, and mixed solvents exposure among the 45,318 factory workers has been published.[2] Briefly, historical records of job descriptions with job-related chemical usage patterns dating back to the 1940s were reviewed, existing environmental assessment reports and historical industrial hygiene surveys were reviewed, and extensive interviews with over 50 long-term workers and walk-through visits of aircraft manufacturing facilities were conducted. There were 784 unique job code and job title combinations identified among factory workers. From this information we identified eight broad occupational families (groups of occupations with similar work activities), as well as specific job titles with potential for the exposure of interest. Individuals were then classified as having routine, intermittent, or no likely exposure to chromates, TCE, PCE and mixed solvents, and the duration of potential exposure to each substance was determined. In general, routine exposure was classified as potential exposure to the chemical of interest as a daily part of work activities, while intermittent exposure was classified as potential exposure during particular shop runs or activities or when assisting other workers. In the absence of historical air sampling information before the 1970s, we classified exposure on a relative scale, assuming that workers who worked daily with specific chemicals received more cumulative exposure than those with less frequent exposure possibilities. The primary exposure metric was based on the specific jobs with exposure potential and the length of time in these jobs.

Statistical Analysis

Mortality was evaluated over a 49-year period, 1960 through 2008. Analyses were on the basis of the underlying cause of death. Observed numbers of deaths from cancers and other diseases were counted by race, sex, age, and calendar year for workers overall and for subgroups defined by duration of employment, specific occupation, and potential for routine and intermittent exposure to chromates, TCE, PCE, or mixed solvents. Since the majority of deaths among cohort members occurred within the state of California, expected numbers of deaths for the cohort were computed based on race, age, calendar year, and sex-specific rates in the general population of California for white workers. To calculate expected numbers of deaths for the smaller number of nonwhite workers in our cohort, US general population rates were used because their racial composition (predominantly African American) was more similar to that of the United States than the state of California, which has a higher proportion of Asian Americans among the nonwhite population. The SMR was calculated as the ratio of the observed number of deaths to the expected number of deaths. The 95% confidence interval (CI) for the SMR was calculated assuming the observed number of deaths followed a Poisson distribution using OCMAP-Plus software (University of Pittsburgh, Pittsburgh, PA).[5] Standardized mortality ratios were calculated for all causes, for all cancers, as well as for site-specific cancers, and for other major cause-of-death categories. Methods based on Poisson regression were used to test for a trend in the SMRs with increasing duration of exposure.[6]

Person-years of follow-up began accruing 1 year after the date of hire or January 1, 1960, whichever came later. Follow-up ended on the date of death, date lost to follow-up, December 31, 2008, or aged 95, whichever occurred first. Workers with unknown vital status ($n = 1336$) or those who died outside the United States ($n = 83$) were considered lost to follow-up and assumed to be alive until their date of last employment at Lockheed Martin or date of last known residential address in the United States, whichever occurred later.

In addition to SMR calculations, internal analyses were also conducted among factory workers, who were potentially exposed to TCE, PCE, mixed solvents or chromates, to evaluate risk of death from specific types of cancer. Duration of employment in specific jobs with potential for exposures of interest was considered the primary measure of cumulative exposure. Workers classified as exposed to TCE, PCE, mixed solvents, or chromates, but for whom duration of exposure was unknown, were excluded from the internal analyses. Cox proportional hazards models,[7] using age as the time scale, were used to estimate relative risks (RR) and corresponding 95% CIs for total cancers and for specific types of cancer and to determine whether there were significant increases in risk with increasing years of potential exposure to specific chemicals. The regression model computed RRs over four categories of years of potential exposure (0, <1, 1–4, ≥5 years), except for analyses of total cancers, in which numbers were large enough to allow expansion of the category of workers with the longest exposure duration into 5 to 9 years and 10 years or more. For internal analyses, workers with intermittent or routine exposure to TCE, PCE, solvents or chromates were compared with the nonexposed referent category of 9520 factory workers who had no exposure to solvents or chromates. Date of birth, date of hire, date of termination, sex, and race (white, nonwhite) were included in the model. Trend analyses were conducted using both continuous duration of employment as well as by including the midpoint of the exposure category as a continuous variable in the Cox proportional hazards regression. When trend analyses were conducted using continuous duration of employment, results were similar to analyses using exposure category midpoints. Guided by published reports and results of our SMR analyses, internal analyses were conducted for cancers of the esophagus, liver, lung, breast, ovary, prostate, testes, kidney, non-Hodgkin lymphoma (NHL), and multiple myeloma. Because it has been suggested that solvents may be multiple organ carcinogens, internal analyses were also performed for all cancer deaths combined.

RESULTS

Descriptive Characteristics

Detailed demographic and employment characteristics of the study cohort were previously published.[1] Briefly, most workers were men (80%), white (91%), and born before 1940 (60%). Approximately 30% of the workers were hired before 1960, and 52% terminated employment before 1980 (data not shown). The study cohort included 32,625 workers employed in non-factory positions and 45,318 factory workers, the majority of whom were employed in assembly (54%) and fabrication (24%). A third of factory workers were employed for 20 or more years. Most factory workers had the potential for routine daily or intermittent exposure to chromates ($n = 7458$; 16.5%), TCE ($n = 5443$; 12.0%), PCE ($n = 5830$; 12.9%), or mixed solvents ($n = 32,735$; 72.2%) (Table 1).

Overall Mortality

Standardized mortality ratios for cancer overall and at specific sites, as well as for other selected causes of death, are presented in Table 2 for factory and non-factory workers. The total person-years of observation was 2,481,666, with an average follow-up time of 31.8 years per worker (SD = 11.0 years); factory and non-factory workers contributed 1,435,459 and 1,046,207 person-years of observation, respectively. Excluding 83 deaths that occurred outside the United States, a total of 34,215 workers had died by the end of follow-up, December 31, 2008; cause of death was obtained for all but 369 (1.1%) of these workers.

Mortality from all causes of death was significantly lower than that of the general population (SMR = 0.91; 95% CI = 0.90–0.92) (Table 2). There were 9041 cancer deaths observed compared with 9396.5 expected, yielding a significantly reduced all-cancer SMR of 0.96 (95% CI = 0.94–0.98). The workers had significantly low risks of death from cancers of the buccal cavity and pharynx, stomach, liver, lung, and cervix. Only the SMR for breast cancer was significantly elevated (SMR = 1.15; 95% CI = 1.02–1.28), based on 320 observed deaths compared with 279.2 expected. Significant reductions in mortality were also observed among workers for several non-cancer causes of death, including heart and cerebrovascular diseases, diabetes, cirrhosis of the liver, nonmalignant respiratory disease, and external causes.

There were 22,661 observed deaths among factory workers and 11,554 deaths among non-factory workers (Table 2). Standardized mortality ratios for most causes of death were lower among non-factory workers than factory workers. Standardized mortality ratios for all cancer deaths were 1.01 (95% CI = 0.99–1.04) among factory workers compared with 0.89 (95% CI = 0.86–0.92) among non-factory workers. The deficit of cancer among non-factory workers was largely due to significantly low rates of death from lung cancer (SMR = 0.79; 95% CI = 0.74–0.85; $n = 866$), for which rates were slightly elevated among factory workers (SMR = 1.05; 95% CI = 1.00–1.10). Mortality from other types of cancer related to smoking (buccal cavity and pharynx, esophagus, larynx, bladder, kidney), as well as from nonmalignant respiratory disease and emphysema, were also lower among non-factory than factory workers. Among factory workers, significantly decreased SMRs were observed for cancers of the buccal cavity and pharynx, stomach and melanoma of the skin. Standardized mortality ratios were significantly increased for cancers of the breast, prostate, and multiple myeloma.

As non-factory workers were classified as having no potential exposure to chemicals,[2] all subsequent analyses and tables are restricted to the 45,318 factory workers.

Duration of Employment

In analyses of factory workers by duration of employment, SMRs were generally highest among short-term workers and decreased with increasing duration of employment (Table 3). The SMRs for all-cancer mortality for those employed 1 to 9, 10 to 19, 20 to 29, and 30 years or more were 1.14, 1.03, 0.94, and 0.91; corresponding patterns were observed for lung cancer (SMRs 1.31, 1.16, 0.99, and 0.73), and nonmalignant respiratory disease (SMRs 1.13, 1.06, 0.89, and 0.77). The number of deaths among those employed 30 years or longer was significantly more than that expected based on general population rates for prostate cancer (SMR = 1.16; 95% CI = 1.01–1.33), NHL (SMR = 1.29; 95% CI = 1.00–1.63), and multiple myeloma (SMR = 1.42; 95% CI = 1.01–1.94). Workers employed for 30 years or more had significantly reduced SMRs for cancer of the buccal cavity and pharynx (SMR = 0.60; 95% CI = 0.35–0.94) and lung (SMR = 0.73; 95% CI = 0.65–0.81).

Specific Occupations

Table 4 presents SMRs for factory workers in seven specific occupations likely to have experienced chemical exposures of interest. Among painters, 94% of whom were classified as exposed to chromates in paints and primers,[2] all-cause mortality was consistent with population expectation (SMR = 1.00; 95% CI = 0.93–1.08), based on 672 observed deaths. The all-cancer (SMR = 1.09; 95% CI = 0.93–1.26) and lung cancer (SMR = 1.24; 95% CI = 0.95–1.59) SMRs among painters were slightly but not significantly increased. More than 65% of the electroplaters and fabrication and structures development mechanics, and almost 50% of the process operators, were exposed to TCE, and more than 70% of the process operators, metal bonders, and fabrication and structures development mechanics were exposed to PCE; all of the process operators and metal bonders were also classified as exposed to chromates.[2] The process operators or electroplaters experienced no significant excess of cancer overall or of cancer of the lung, kidney or NHL. An

TABLE 2. Standardized Mortality Ratios for Lockheed Martin Factory and Non-Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 (Sex and Race Combined)

	Factory				Non-Factory				Total			
Persons at risk	**45,318**				**32,625**				**77,943**			
Person-years	**1,435,459**				**1,046,207**				**2,481,666**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
All causes of death (001–999)	22,661	23,450.4	0.97	0.95–0.98	11,554	14,164.7	0.82	0.80–0.83	34,215	37,615.1	0.91	0.90–0.92
All malignant neoplasms (140–208)	5,782	5,721.5	1.01	0.99–1.04	3,259	3,675.0	0.89	0.86–0.92	9,041	9,396.5	0.96	0.94–0.98
Buccal cavity and pharynx (140–149)	106	133.6	0.79	0.65–0.96	57	79.3	0.72	0.54–0.93	163	212.9	0.77	0.65–0.89
Esophagus (150)	164	158.0	1.04	0.89–1.21	83	95.0	0.87	0.70–1.08	247	253.0	0.98	0.86–1.11
Stomach (151)	150	200.7	0.75	0.63–0.88	80	114.9	0.70	0.55–0.87	230	315.6	0.73	0.64–0.83
Colon (153)	519	476.8	1.09	1.00*–1.19	262	295.2	0.89	0.78–1.00*	781	772.0	1.01	0.94–1.09
Rectum (154)	107	106.1	1.01	0.83–1.22	46	63.6	0.72	0.53–0.96	153	169.8	0.90	0.76–1.06
Biliary passages and liver (155, 156)	143	159.2	0.90	0.76–1.06	79	103.4	0.76	0.61–0.95	222	262.6	0.85	0.74–0.96
Pancreas (157)	309	307.3	1.01	0.90–1.12	201	197.6	1.02	0.88–1.17	510	504.9	1.01	0.92–1.10
Larynx (161)	52	58.7	0.89	0.66–1.16	24	33.6	0.72	0.46–1.06	76	92.3	0.82	0.65–1.03
Bronchus, trachea, and lung (162)	1,818	1,733.7	1.05	1.00–1.10	866	1,093.5	0.79	0.74–0.85	2,684	2,827.2	0.95	0.91–0.99
Bone (170)	11	11.7	0.94	0.47–1.68	7	7.2	0.97	0.39–2.00	18	19.0	0.95	0.56–1.50
Connective and other soft tissue (171)	34	31.4	1.08	0.75–1.51	21	21.8	0.97	0.60–1.48	55	53.2	1.04	0.78–1.35
Melanoma of skin (172)	70	91.9	0.76	0.59–0.96	67	64.9	1.03	0.80–1.31	137	156.8	0.87	0.73–1.03
Breast (174, 175)	153	128.6	1.19	1.01–1.39	167	150.5	1.11	0.95–1.29	320	279.2	1.15	1.02–1.28
All uterine (females only) (179–182)	27	35.5	0.76	0.50 –1.11	31	37.3	0.83	0.57–1.18	58	72.8	0.80	0.61–1.03
Cervix uteri (180)	12	15.5	0.77	0.40–1.35	9	17.1	0.53	0.24–1.00*	21	32.6	0.65	0.40–0.99
Ovary and other female genital (183, 184)	45	44.0	1.02	0.75–1.37	57	52.3	1.09	0.83–1.41	102	96.2	1.06	0.86–1.29
Prostate (males only) (185)	588	537.5	1.09	1.01–1.19	280	290.8	0.96	0.85–1.08	868	828.3	1.05	0.98–1.12
Testes and other male genital (186,187)	19	12.3	1.55	0.93–2.41	1	7.0	0.14	0.00–0.79	20	19.3	1.04	0.63–1.60
Kidney (189.0–189.2)	146	132.9	1.10	0.93–1.29	83	86.3	0.96	0.77–1.19	229	219.2	1.05	0.91–1.19
Bladder and other urinary (188,189.3–189.9)	161	163.1	0.99	0.84–1.15	79	97.5	0.81	0.64–1.01	240	260.7	0.92	0.81–1.05
Brain and CNS (191, 192)	129	139.9	0.92	0.77–1.10	106	96.9	1.09	0.90–1.32	235	236.8	0.99	0.87–1.13
Thyroid and other endocrine glands (193, 194)	18	17.4	1.03	0.61–1.63	14	12.0	1.17	0.64–1.96	32	29.4	1.09	0.75–1.54
Non-Hodgkin lymphoma (200, 202)	221	211.7	1.04	0.91–1.19	162	142.0	1.14	0.97–1.33	383	353.7	1.08	0.98–1.20
Hodgkin disease (201)	23	22.9	1.01	0.64–1.51	14	14.3	0.98	0.54–1.65	37	37.1	1.00	0.70–1.37
Multiple myeloma (203)	130	102.5	1.27	1.06–1.51	57	64.9	0.88	0.67–1.14	187	167.3	1.12	0.96–1.29
Leukemia and aleukemia (204–208)	212	212.0	1.00	0.87–1.14	150	136.7	1.10	0.93–1.29	362	348.7	1.04	0.93–1.15
Chronic lymphocytic leukemia (204.1)	54	42.8	1.26	0.95–1.65	25	26.3	0.95	0.61–1.40	79	69.1	1.14	0.91–1.43

(*Continues*)

TABLE 2. Standardized Mortality Ratios for Lockheed Martin Factory and Non-Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 (Sex and Race Combined) *(Continued)*

	Factory				Non-Factory				Total			
Persons at risk	**45,318**				**32,625**				**77,943**			
Person-years	**1,435,459**				**1,046,207**				**2,481,666**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
Leukemia other than CLL	157	169.2	0.93	0.79–1.09	124	110.4	1.12	0.93–1.34	281	279.7	1.01	0.89–1.13
AIDS (042–044, 795.8)	64	199.4	0.32	0.25–0.41	26	122.4	0.21	0.14–0.31	90	321.8	0.28	0.23–0.34
Smoking related cancers (140–150, 157, 161, 162, 188–189)	2,756	2,687.4	1.03	0.99–1.07	1,393	1,682.8	0.83	0.79–0.87	4,149	4,370.2	0.95	0.92–0.98
Diabetes (250)	455	467.1	0.97	0.89–1.07	210	306.7	0.69	0.60–0.78	665	773.8	0.86	0.80–0.93
Mental and behavioral disorders (290–319)	304	287.1	1.06	0.94–1.19	165	178.0	0.93	0.79–1.08	469	465.0	1.01	0.92–1.10
Diseases of the nervous system (320–389)	571	593.0	0.96	0.89–1.05	423	377.6	1.12	1.02–1.23	994	970.6	1.02	0.96–1.09
Cerebrovascular disease (430–438)	1,380	1,501.9	0.92	0.87–0.97	722	862.9	0.84	0.78–0.90	2,102	2,364.8	0.89	0.85–0.93
All heart disease (390–398, 404, 410–429)	7,990	8,146.5	0.98	0.96–1.00*	3,839	4,673.7	0.82	0.80–0.85	11,829	12,820.2	0.92	0.91–0.94
Nonmalignant respiratory disease (460–519)	2,054	2,170.6	0.95	0.91–0.99	958	1,330.7	0.72	0.68–0.77	3,012	3,501.3	0.86	0.83–0.89
Bronchitis, emphysema, asthma (490–493)	746	678.4	1.10	1.02–1.18	344	467.7	0.74	0.66–0.82	1,090	1,146.1	0.95	0.90–1.01
Cirrhosis of liver (571)	436	625.0	0.70	0.63–0.77	227	394.2	0.58	0.50–0.66	663	1,019.2	0.65	0.60–0.70
Nephritis and nephrosis (580–589)	213	184.0	1.16	1.01–1.32	92	107.3	0.86	0.69–1.05	305	291.3	1.05	0.93–1.17
All external causes of death (800–999)	1,357	1,580.0	0.86	0.81–0.91	557	942.8	0.59	0.54–0.64	1,914	2,522.8	0.76	0.73–0.79
Accidents (850–949)	798	940.2	0.85	0.79–0.91	332	559.5	0.59	0.53–0.66	1,130	1,499.6	0.75	0.71–0.80
Suicides (950–959)	366	415.6	0.88	0.79–0.98	184	264.7	0.70	0.60–0.80	550	680.3	0.81	0.74 –0.88
Unknown causes of death	217				152				369			

Obs, observed; Exp, expected; SMR, standardized mortality ratio; CI, confidence interval; CNS, central nervous system; CLL, chronic lymphocytic leukemia.
*Confidence interval does not exclude 1.00.

TABLE 3. Standardized Mortality Ratios for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 by Duration of Employment (Sex and Race Combined)

	1–9 years				10–19 years				20–29 years				≥30 years			
Person-years	**729,558**				**315,479**				**230,767**				**159,759**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
All causes of death (001–999)	7,228	6,748.4	1.07	1.05–1.10	4,970	4,996.7	1.00	0.97–1.02	5,353	5,843.7	0.92	0.89–0.94	5,110	5,862.5	0.87	0.85–0.90
All malignant neoplasms (140–208)	1,915	1,679.0	1.14	1.09–1.19	1,241	1,202.3	1.03	0.98–1.09	1,291	1,369.5	0.94	0.89–1.00	1,335	1,471.0	0.91	0.86–0.96
Buccal cavity and pharynx (140–149)	40	41.6	0.96	0.69–1.31	25	29.0	0.86	0.56–1.27	23	32.8	0.70	0.44–1.05	18	30.2	0.60	0.35–0.94
Esophagus (150)	55	50.5	1.09	0.82–1.42	32	32.8	0.98	0.67–1.38	39	35.7	1.09	0.78–1.50	38	39.1	0.97	0.69–1.33
Stomach (151)	45	56.3	0.80	0.58–1.07	43	44.1	0.97	0.71–1.31	25	52.1	0.48	0.31–0.71	37	48.3	0.77	0.54–1.06
Colon (153)	145	129.8	1.12	0.94–1.32	108	100.1	1.08	0.89–1.30	125	120.2	1.04	0.87–1.24	141	126.7	1.11	0.94–1.31
Rectum (154)	27	29.5	0.91	0.60–1.33	25	23.4	1.07	0.69–1.58	27	28.1	0.96	0.63–1.40	28	25.1	1.12	0.74–1.61
Biliary passages and liver (155,156)	54	53.3	1.01	0.76–1.32	28	32.9	0.85	0.57–1.23	32	34.7	0.92	0.63–1.30	29	38.4	0.76	0.51–1.09
Pancreas (157)	106	90.7	1.17	0.96–1.41	64	65.0	0.99	0.76–1.26	71	74.3	0.96	0.75–1.21	68	77.3	0.88	0.68–1.12
Larynx (161)	24	17.6	1.36	0.87–2.02	5	12.4	0.40	0.13–0.94	10	14.3	0.70	0.34–1.28	13	14.3	0.91	0.48–1.56
Bronchus, trachea, and lung (162)	669	511.1	1.31	1.21–1.41	416	359.5	1.16	1.05–1.27	404	410.1	0.99	0.89–1.09	329	453.1	0.73	0.65–0.81
Bone (170)	5	4.0	1.24	0.40–2.88	1	2.6	0.39	0.01–2.15	1	2.8	0.36	0.01–2.00	4	2.3	1.72	0.47–4.41
Connective and other soft tissue (171)	16	11.3	1.42	0.81–2.31	6	6.6	0.92	0.34–1.99	5	6.5	0.77	0.25–1.80	7	7.1	0.99	0.40–2.03
Melanoma of skin (172)	32	35.0	0.91	0.63–1.29	14	18.6	0.75	0.41–1.26	7	17.8	0.39	0.16–0.81	17	20.5	0.83	0.48–1.33
Breast (174, 175)	43	36.8	1.17	0.85–1.58	40	36.5	1.10	0.78–1.49	42	35.0	1.20	0.87–1.62	28	20.3	1.38	0.92–1.99
All uterine (females only) (179–182)	5	9.3	0.54	0.17–1.25	8	10.6	0.75	0.33–1.49	9	10.4	0.87	0.40–1.65	5	5.2	0.97	0.31–2.25
Cervix uteri (180)	2	4.8	0.41	0.05–1.49	5	4.9	1.02	0.33–2.37	3	4.1	0.73	0.15–2.12	2	1.6	1.24	0.15–4.49
Ovary and other female genital (183, 184)	14	11.4	1.23	0.67–2.07	13	12.6	1.04	0.55–1.77	11	12.7	0.87	0.43–1.56	7	7.4	0.95	0.38–1.95
Prostate (males only) (185)	129	123.4	1.05	0.87–1.24	123	102.0	1.21	1.00–1.44	130	134.1	0.97	0.81–1.15	206	178.0	1.16	1.01–1.33
Testes and other male genital (186,187)	7	6.1	1.15	0.46–2.38	5	2.6	1.96	0.64–4.57	3	2.1	1.46	0.30–4.26	4	1.6	2.49	0.68–6.36
Kidney (189.0–189.2)	52	42.9	1.21	0.91–1.59	29	27.4	1.06	0.71–1.52	39	30.0	1.30	0.93–1.78	26	32.7	0.80	0.52–1.17
Bladder and other urinary (188,189.3–189.9)	56	41.8	1.34	1.01–1.74	29	33.0	0.88	0.59–1.26	32	41.0	0.78	0.53–1.10	44	47.4	0.93	0.68–1.25
Brain and CNS (191, 192)	53	51.4	1.03	0.77–1.35	19	29.7	0.64	0.39–1.00	24	29.9	0.80	0.52–1.20	33	29.0	1.14	0.78–1.60
Thyroid and other endocrine glands (193, 194)	5	5.7	0.87	0.28–2.03	4	3.8	1.04	0.28–2.66	5	4.1	1.23	0.40–2.86	4	3.8	1.06	0.29–2.72
Non-Hodgkin lymphoma (200, 202)	59	67.0	0.88	0.67–1.14	41	43.5	0.94	0.68–1.28	52	47.5	1.10	0.82–1.44	69	53.6	1.29	1.00–1.63
Hodgkin disease (201)	7	9.2	0.76	0.31–1.57	6	5.3	1.14	0.42–2.48	8	5.1	1.57	0.68–3.08	2	3.3	0.61	0.07–2.18
Multiple myeloma (203)	39	29.8	1.31	0.93–1.79	29	21.2	1.37	0.92–1.96	23	24.0	0.96	0.61–1.44	39	27.4	1.42	1.01–1.94
Leukemia and aleukemia (204–208)	77	65.0	1.18	0.93–1.48	27	43.9	0.62	0.41–0.90	48	49.0	0.98	0.72–1.30	60	54.2	1.11	0.85–1.43
Chronic lymphocytic leukemia (204.1)	20	11.3	1.78	1.08–2.74	5	8.7	0.58	0.19–1.34	18	10.6	1.70	1.01–2.69	11	12.2	0.90	0.45–1.61

(*Continues*)

TABLE 3. Standardized Mortality Ratios for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 by Duration of Employment (Sex and Race Combined) *(Continued)*

	1–9 years				10–19 years				20–29 years				≥30 years			
Person-years	**729,558**				**315,479**				**230,767**				**159,759**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
Leukemia other than CLL	57	53.8	1.06	0.80–1.37	22	35.2	0.63	0.39–0.95	30	38.4	0.78	0.53–1.12	48	41.9	1.15	0.84–1.52
AIDS (042–044,795.8)	43	130.6	0.33	0.24–0.44	14	42.0	0.33	0.18–0.56	5	18.1	0.28	0.09–0.64	2	8.7	0.23	0.03–0.83
Smoking related cancers (140–150,157,161–162,188–189)	1,002	796.2	1.26	1.18–1.34	600	559.1	1.07	0.99–1.16	618	638.1	0.97	0.89–1.05	536	694.1	0.77	0.71–0.84
Diabetes (250)	169	146.3	1.16	0.99–1.34	81	98.6	0.82	0.65–1.02	107	104.4	1.03	0.84–1.24	98	117.8	0.83	0.68–1.01
Mental and behavioral disorders (290–319)	102	93.0	1.10	0.90–1.33	61	58.3	1.05	0.80–1.34	66	63.0	1.05	0.81–1.33	75	72.7	1.03	0.81–1.29
Diseases of the nervous system (320–389)	140	151.9	0.92	0.78–1.09	138	130.4	1.06	0.89–1.25	127	147.5	0.86	0.72–1.03	166	163.2	1.02	0.87–1.18
Cerebrovascular disease (430–438)	368	344.8	1.07	0.96–1.18	292	332.5	0.88	0.78–0.99	403	425.8	0.95	0.86–1.04	317	398.9	0.80	0.71–0.89
All heart disease (390–398, 404, 410–429)	2,190	2,052.9	1.07	1.02–1.11	1,819	1,750.6	1.04	0.99–1.09	2,097	2,208.2	0.95	0.91–0.99	1,884	2,135.1	0.88	0.84–0.92
Nonmalignant respiratory disease (460–519)	594	526.8	1.13	1.04–1.22	465	439.2	1.06	0.97–1.16	495	555.4	0.89	0.81–0.97	500	649.2	0.77	0.70–0.84
Bronchitis, emphysema, asthma (490–493)	230	187.0	1.23	1.08–1.40	184	138.9	1.32	1.14–1.53	167	158.8	1.05	0.90–1.22	165	193.7	0.85	0.73–0.99
Cirrhosis of liver (571)	185	240.5	0.77	0.66–0.89	91	143.5	0.63	0.51–0.78	88	140.4	0.63	0.50–0.77	72	100.8	0.72	0.56–0.90
Nephritis & nephrosis (580–589)	64	50.4	1.27	0.98–1.62	52	39.0	1.33	1.00*–1.75	53	44.5	1.19	0.89–1.56	44	50.1	0.88	0.64–1.18
All external causes of death (800–999)	762	770.2	0.99	0.92–1.06	266	341.6	0.78	0.69–0.88	164	276.9	0.59	0.51–0.69	165	191.6	0.86	0.74–1.00*
Accidents (850–949)	434	447.2	0.97	0.88–1.07	147	203.9	0.72	0.61–0.85	106	171.1	0.62	0.51–0.75	111	117.9	0.94	0.77–1.13
Suicides (950–959)	190	189.7	1.00	0.86–1.15	85	89.6	0.95	0.76–1.17	43	78.7	0.55	0.40–0.74	48	57.7	0.83	0.61–1.10
Unknown causes of death	113				42				45				17			

Obs, observed; Exp, expected; SMR, standardized mortality ratio; CI, confidence interval; CNS, central nervous system; CLL, chronic lymphocytic leukemia.
*Confidence interval does not exclude 1.00.

TABLE 4. Standardized Mortality Ratios for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 by Specific Occupation (Sex and Race Combined)

	Painter				Process Operator or Electroplater*				Plastic Parts Fabricator			
Persons at risk	**1,216**				**1,551**				**2,681**			
Person-years	**36,678**				**47,191**				**82,458**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
All causes of death (001–999)	672	671.4	1.00	0.93–1.08	692	704.3	0.98	0.91–1.06	1,012	1,055.5	0.96	0.90–1.02
All malignant neoplasms (140–208)	174	160.3	1.09	0.93–1.26	176	175.4	1.00	0.86–1.16	262	266.5	0.98	0.87–1.11
Esophagus (150)	6	4.7	1.27	0.47–2.76	5	5.1	0.97	0.32–2.27	7	8.2	0.86	0.35–1.77
Biliary passages and liver (155, 156)	3	4.4	0.68	0.14–1.98	6	5.2	1.16	0.43–2.53	8	8.2	0.97	0.42–1.92
Pancreas (157)	10	8.5	1.17	0.56–2.16	12	9.5	1.27	0.66–2.22	13	14.3	0.91	0.49–1.56
Bronchus, trachea, and lung (162)	61	49.2	1.24	0.95–1.59	51	52.8	0.97	0.72–1.27	91	82.4	1.10	0.89–1.36
Breast (174, 175)	1	1.8	0.56	0.01–3.13	6	5.7	1.06	0.39–2.30	10	5.5	1.81	0.87–3.32
Ovary and other female genital (183, 184)	0	0.6	0.00	0.00–6.31	4	2.0	2.05	0.56–5.24	1	1.7	0.58	0.02–3.25
Prostate (males only) (185)	22	17.1	1.29	0.81–1.95	16	15.0	1.07	0.61–1.73	25	23.4	1.07	0.69–1.58
Testes and other male genital (186, 187)	2	0.3	5.79	0.70–20.92	0	0.4	0.00	0.00–10.05	1	0.6	1.56	0.04–8.69
Kidney (189.0–189.2)	3	3.7	0.82	0.17–2.40	2	3.9	0.51	0.06–1.84	11	6.4	1.73	0.86–3.09
Non-Hodgkin lymphoma (200, 202)	4	5.6	0.71	0.19–1.82	8	6.2	1.29	0.56–2.55	13	9.9	1.32	0.70–2.26
Multiple myeloma (203)	5	2.9	1.72	0.56–4.02	0	3.3	0.00	0.00–1.13	4	4.9	0.81	0.22–2.08
Leukemia and aleukemia (204–208)	5	5.8	0.86	0.28–2.00	7	6.2	1.13	0.46–2.33	3	9.7	0.31	0.06–0.90

(*Continues*)

TABLE 4. Standardized Mortality Ratios for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 by Specific Occupation (Sex and Race Combined) (*Continued*)

	Welder				Metal Bonder				Fabrication and Structures Development Mechanic				Final Assembler			
Persons at risk	**811**				**1,162**				**2,425**				**20,895**			
Person-years	**25,512**				**33,733**				**73,048**				**660,576**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
All causes of death (001–999)	558	636.1	0.88	0.81–0.95	443	415.3	1.07	0.97–1.17	1,751	2,066.0	0.85	0.81–0.89	10,953	11,271.8	0.97	0.95–0.99
All malignant neoplasms (140-208)	163	150.1	1.09	0.93–1.27	123	102.9	1.20	0.99–1.43	428	500.1	0.86	0.78–0.94	2,726	2,732.1	1.00	0.96–1.04
Esophagus (150)	4	4.0	1.00	0.27–2.56	5	3.3	1.53	0.50–3.56	12	13.9	0.86	0.45–1.50	71	76.9	0.92	0.72–1.17
Biliary passages and liver (155,156)	5	3.8	1.33	0.43–3.11	2	3.3	0.61	0.07–2.20	12	12.6	0.95	0.49–1.67	71	75.6	0.94	0.73–1.19
Pancreas (157)	9	7.9	1.14	0.52–2.16	5	5.5	0.91	0.29–2.11	23	26.0	0.88	0.56–1.33	148	146.0	1.01	0.86–1.19
Bronchus, trachea, and lung (162)	50	46.4	1.08	0.80–1.42	41	32.0	1.28	0.92–1.74	111	157.7	0.70	0.58–0.85	844	832.5	1.01	0.95–1.09
Breast (174, 175)	2	1.1	1.89	0.23–6.82	2	1.5	1.37	0.17–4.97	1	1.1	0.92	0.02–5.11	55	50.9	1.08	0.81–1.41
Ovary and other female genital organs (183-184)	0	0.3	0.00	0.00–11.18	0	0.4	0.00	0.00–8.80	0	0.2	0.00	0.00–20.79	13	17.2	0.76	0.40–1.30
Prostate (males only) (185)	20	17.6	1.14	0.69–1.75	9	9.1	0.99	0.45–1.89	67	62.4	1.07	0.83–1.36	304	269.4	1.13	1.01–1.26
Testes and other male genital organs (186,187)	0	0.3	0.00	0.00–13.67	1	0.3	3.73	0.09–20.78	2	0.8	2.48	0.30–8.97	12	5.8	2.07	1.07–3.61
Kidney (189.0–189.2)	4	3.4	1.17	0.32–2.99	6	2.5	2.40	0.88–5.23	6	11.3	0.53	0.20–1.16	63	63.1	1.00	0.77–1.28
Non-Hodgkin lymphoma (200,202)	4	5.4	0.74	0.20–1.89	6	3.8	1.59	0.58–3.46	26	17.6	1.48	0.96–2.16	110	100.0	1.10	0.90–1.33
Multiple myeloma (203)	6	2.6	2.27	0.83–4.94	3	1.9	1.58	0.33–4.62	12	9.0	1.33	0.69–2.33	64	49.3	1.30	1.00–1.66
Leukemia and aleukemia (204–208)	5	5.6	0.89	0.29–2.07	2	3.8	0.53	0.06–1.92	10	18.4	0.54	0.26–1.00	93	100.8	0.92	0.75–1.13

*In the original analysis, the number of process operators and electroplaters was erroneously summed to 1626. There were 75 factory workers who were both process operators and electroplaters during the course of their employment at Lockheed Martin.

Obs, observed; Exp, expected; CI, confidence interval; ICD-9, International Classification of Diseases, Ninth Revision; SMR, standardized mortality ratio.

increased all-cancer SMR of 1.20 (95% CI = 0.99–1.43), of borderline significance, was observed among metal bonders, who also had nonsignificantly elevated SMRs for lung cancer, kidney cancer, NHL, and multiple myeloma; however, the small number of deaths from several of these cancers precludes meaningful interpretation. Mortality from cancer overall (SMR = 0.86; 95% CI = 0.78–0.94), and from lung cancer in particular (SMR = 0.70; 95% CI = 0.58–0.85), was significantly low among fabrication and structures development mechanics, while risk of death from NHL was nonsignificantly elevated. Significantly elevated SMRs for cancer of the prostate and testes and for multiple myeloma were observed among the large group of final assemblers (Table 4).

Exposure to Chromates, TCE, PCE and Mixed Solvents

Table 5 presents SMRs for factory workers classified by exposure to chromates, TCE, PCE, or mixed solvents. For many types of cancer, observed numbers of deaths were too small for meaningful interpretation. Standardized mortality ratios for all causes (SMR = 0.96; 95% CI = 0.93–0.99) and all cancers (SMR = 0.99; 95% CI = 0.92–1.05) were slightly below expectation for the 7458 workers routinely or intermittently exposed to chromates. There were no significantly elevated or decreased SMRs for any type of cancer. Mortality from lung cancer was nonsignificantly reduced compared with the general population, with 291 observed deaths and 306.7 expected. Non-cancer mortality was typically near expectation, with the exception of a significantly elevated SMR for bronchitis, emphysema, and asthma.

Among the 5443 factory workers exposed to TCE, no significantly elevated SMRs were observed for any cancer or non-cancer cause of death. Overall cancer mortality was significantly low, with a SMR of 0.92 (95% CI = 0.86–0.97). The observed number of lung cancer deaths among workers was significantly lower than that expected in the general population (SMR = 0.80; 95% CI = 0.71–0.90). Liver and kidney cancer SMRs were both nonsignificantly reduced, while the SMR for NHL was nonsignificantly elevated (Table 5).

We observed 2641 deaths among the 5830 workers exposed to PCE. The all-cancer SMR was 0.96 (95% CI = 0.89–1.04), based on 679 deaths observed versus 706.9 expected. Mortality for NHL (SMR = 1.43) was significantly elevated, while for stomach cancer it was significantly reduced (SMR = 0.60). The SMR for kidney cancer was nonsignificantly reduced, and for breast cancer it was nonsignificantly elevated (Table 5).

Over 70% of the factory workers had mixed-solvent exposures (N = 32,735) (Table 5), with SMR patterns comparable to those seen for all factory workers (Table 2). The all-cause SMR was significantly low (SMR = 0.97), based on 16,826 deaths observed versus 17,401.1 expected, while the total cancer SMR was 1.00. Seventeen testicular or other male genital cancer deaths were observed, yielding a significantly elevated SMR of 1.86 (95% CI = 1.08–2.98). The SMRs for multiple myeloma (SMR = 1.27; 95% CI = 1.03–1.55) and colon cancer (SMR = 1.11; 95% CI = 1.00–1.23) were also significantly elevated, and the SMRs for cancer of the buccal cavity and pharynx and stomach were significantly low. Mortality due to liver cancer, kidney cancer, NHL and most other cancer sites was near or below population expectations.

Standardized mortality ratios calculated only for factory workers with daily exposures to the chemicals of interest showed similar patterns to those presented in Table 5 for workers with daily and intermittent exposure combined. However, substantially fewer numbers of deaths resulted in decreased stability of the SMR estimates (data presented in an online supplement, http://links.lww.com/JOM/A70).

Internal Cohort Comparisons

Table 6 presents RRs from internal comparisons for total cancers and for specific sites among factory workers by duration of exposure to TCE, PCE, and mixed solvents. There were a total of 971 cancer deaths observed among those with potential for exposure to TCE, with a nonsignificantly reduced RR among those with the longest duration of potential TCE exposure. No significant trends were observed in risk of death from total cancers or any particular cancer, including kidney cancer and NHL, by years of exposure to TCE, with the exception of a significant ($P < 0.01$) negative trend in lung cancer risk with increasing duration of exposure; the RR for lung cancer was 0.66 (95% CI = 0.49–0.89) among those with 5 or more years of exposure to TCE (Table 6).

Among factory workers potentially exposed to PCE, no significant trends in risk of death by years of exposure to PCE for total cancers or for specific cancer sites were observed (Table 6). A nonsignificant elevation in risk of death for total cancers was observed among those exposed for 1 to 4 years (RR = 1.15, 95% CI = 1.00–1.32), while those exposed for 5 or more years had a nonsignificant decrease in risk. Decreased RRs were observed for kidney cancer among workers in all categories of PCE exposure duration. Relative risks for NHL and breast cancer were nonsignificantly elevated across most categories of PCE exposure duration, while liver cancer risk was low for all but those exposed 5 or more years (Table 6).

Overall, 3585 cancers were observed among the 32,735 workers exposed to mixed solvents, yielding RRs close to or below 1.0 in all duration categories (Table 6). Among those workers with 10 or more years' exposure to mixed solvents, the total cancer RR was 0.93 (95% CI = 0.86–1.01) (P-trend = 0.06). A significant decreasing trend in risk with increasing years of exposure was observed for kidney cancer (P-trend = 0.03) (Table 6) and for ovarian cancer (P = 0.03) (data not shown). The RRs for testicular cancer were nonsignificantly elevated among those with 1 to 4 years (RR = 3.47; 95% CI = 0.72–16.79) and 5 or more years (RR = 1.72; 95% CI = 0.35–8.57) of exposure to mixed solvents (P-trend > 0.20) (data not shown). The numbers of deaths due to testicular or ovarian cancer among workers with exposure to TCE or PCE were too small for meaningful interpretation (Table 5).

No significant RRs or trends in risk were observed for factory workers with exposure to chromates (data not shown). Relative risks for lung cancer among workers exposed to chromates for less than 1, 1 to 4, and 5 years or more were 0.96 (95% CI = 0.78–1.17), 1.05 (95% CI = 0.84–1.32), and 1.07 (95% CI = 0.78–1.47), respectively (P-trend = 0.54). Overall, 947 total cancers were observed among chromate exposed workers, with corresponding RRs of 0.99 (95% CI = 0.88–1.10), 1.08 (95% CI = 0.95–1.22), and 1.15 (95% CI = 0.97–1.36) (P-trend = 0.06).

DISCUSSION

Our extended mortality follow-up of the Burbank aircraft manufacturing cohort identified almost 14,000 additional deaths since the previous report,[1] including 3573 additional cancer deaths. On the basis of 34,215 deaths among 77,943 workers, there was little evidence of increased cancer or other disease risk associated with employment in aircraft manufacturing. Most SMRs were close to or less than 1.0 (Table 2), and the changes in SMRs from the first study[1] to this study were largely consistent with the diminution of the healthy worker effect with the passage of time since first employment[8]; the all-cause SMR increased from 0.83 to 0.91, the all-cancer SMR increased from 0.90 to 0.96, and the all-heart disease SMR increased from 0.86 to 0.92. Because of the extremely long follow-up of the Burbank cohort, which spanned 49 years, the impact of the healthy worker effect on the reported SMRs is now relatively minor.

TABLE 5. Standardized Mortality Ratios for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 for Exposure to Selected Agents (Sex and Race Combined)*

	Chromates				Trichloroethylene				Perchloroethylene				Mixed Solvents			
Persons at risk	**7,458**				**5,443**				**5,830**				**32,735**			
Person-years	**226,885**				**180,704**				**164,912**				**1,031,808**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
All causes of death (001–999)	3,913	4,091.8	0.96	0.93–0.99	4,070	4,498.9	0.91	0.88–0.93	2,641	2,851.2	0.93	0.89–0.96	16,826	17,401.1	0.97	0.95–0.98
All malignant neoplasms (140–208)	980	995.0	0.99	0.92–1.05	986	1,077.4	0.92	0.86–0.97	679	706.9	0.96	0.89–1.04	4,232	4,217.1	1.00	0.97–1.03
Buccal cavity and pharynx (140-149)	16	23.7	0.67	0.39–1.10	21	25.2	0.83	0.52–1.27	13	16.8	0.77	0.41–1.32	71	99.9	0.71	0.56–0.90
Esophagus (150)	27	28.9	0.94	0.62–1.36	19	29.3	0.65	0.39–1.01	24	21.3	1.13	0.72–1.68	121	118.5	1.02	0.85–1.22
Stomach (151)	26	36.4	0.72	0.47–1.05	31	39.8	0.78	0.53–1.10	15	25.0	0.60	0.34–0.99	102	150.6	0.68	0.55–0.82
Colon (153)	95	82.8	1.15	0.93–1.40	104	91.9	1.13	0.92–1.37	64	58.0	1.10	0.85–1.41	391	351.9	1.11	1.00–1.23
Rectum (154)	12	18.4	0.65	0.34–1.14	20	20.8	0.96	0.59–1.49	10	12.3	0.82	0.39–1.50	83	78.8	1.05	0.84–1.31
Biliary passages and liver (155,156)	24	27.6	0.87	0.56–1.30	24	26.9	0.89	0.57–1.33	19	20.5	0.93	0.56–1.45	102	116.9	0.87	0.71–1.06
Pancreas (157)	56	52.8	1.06	0.80–1.38	53	56.9	0.93	0.70–1.22	39	37.1	1.05	0.75–1.44	226	225.6	1.00	0.88–1.14
Larynx (161)	10	10.8	0.92	0.44–1.70	8	11.5	0.70	0.30–1.37	7	7.8	0.90	0.36–1.84	43	44.4	0.97	0.70–1.31
Bronchus, trachea, and lung (162)	291	306.7	0.95	0.84–1.06	267	333.7	0.80	0.71–0.90	206	220.3	0.94	0.81–1.07	1,333	1,288.1	1.04	0.98–1.09
Bone (170)	2	2.0	1.00	0.12–3.60	3	2.1	1.43	0.29–4.17	0	1.4	0.00	0.00–2.71	9	8.7	1.04	0.47–1.97
Connective and other soft tissue (171)	4	5.2	0.77	0.21–1.97	3	5.1	0.58	0.12–1.70	6	3.8	1.58	0.58–3.43	23	22.8	1.01	0.64–1.51
Melanoma of skin (172)	13	14.7	0.89	0.47–1.51	14	15.2	0.92	0.50–1.55	10	10.6	0.95	0.45–1.74	54	67.1	0.81	0.61–1.05
Breast (174, 175)	18	14.7	1.22	0.72–1.93	12	11.6	1.03	0.53–1.80	12	7.9	1.52	0.78–2.65	83	72.6	1.14	0.91–1.42
All uterine (females only) (179–182)	1	4.0	0.25	0.01–1.39	1	3.2	0.32	0.01–1.77	1	2.0	0.50	0.01–2.80	13	20.3	0.64	0.34–1.09
Cervix uteri (180)	1	1.8	0.57	0.01–3.16	0	1.3	0.00	0.00–2.87	1	0.9	1.09	0.03–6.04	5	9.0	0.56	0.18–1.30
Ovary and other female genital (183-184)	7	4.8	1.45	0.58–2.98	4	4.0	1.01	0.28–2.59	3	2.3	1.28	0.26–3.74	24	24.3	0.99	0.63–1.47
Prostate (males only) (185)	115	103.6	1.11	0.92–1.33	135	122.0	1.11	0.93–1.31	71	77.1	0.92	0.72–1.16	452	416.1	1.09	0.99–1.19
Testes and other male genital (186,187)	5	2.0	2.44	0.79–5.70	3	2.0	1.53	0.32–4.46	3	1.4	2.18	0.45–6.37	17	9.1	1.86	1.08–2.98
Kidney (189.0-189.2)	19	22.7	0.84	0.50–1.31	16	24.2	0.66	0.38–1.07	13	16.3	0.80	0.43–1.37	101	98.2	1.03	0.84–1.25
Bladder and other Urinary (188,189.3-189.9)	31	28.8	1.08	0.73–1.53	35	34.0	1.03	0.72–1.43	17	20.2	0.84	0.49–1.35	123	122.8	1.00	0.83–1.20
Brain and CNS (191-192)	20	22.7	0.88	0.54–1.36	20	23.4	0.85	0.52–1.32	16	16.0	1.00	0.57–1.63	98	101.9	0.96	0.78–1.17
Thyroid & other endocrine glands (193-194)	5	2.9	1.75	0.57–4.09	4	3.0	1.34	0.37–3.43	2	1.9	1.03	0.13–3.72	15	12.6	1.19	0.67–1.97
Non-Hodgkin lymphoma (200,202)	46	35.4	1.30	0.95–1.73	50	38.2	1.31	0.97–1.73	36	25.1	1.43	1.00–1.98	161	155.0	1.04	0.88–1.21
Hodgkins disease (201)	6	3.8	1.59	0.58–3.46	5	4.0	1.25	0.41–2.91	1	2.4	0.42	0.01–2.35	16	16.8	0.95	0.54–1.55

(*Continues*)

TABLE 5. Standardized Mortality Ratios for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 for Exposure to Selected Agents (Sex and Race Combined)* *(Continued)*

	Chromates				Trichloroethylene				Perchloroethylene				Mixed Solvents			
Persons at risk	**7,458**				**5,443**				**5,830**				**32,735**			
Person-years	**226,885**				**180,704**				**164,912**				**1,031,808**			
Cause of death (ICD-9)	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**	**Obs**	**Exp**	**SMR**	**95% CI**
Multiple myeloma (203)	19	18.1	1.05	0.63–1.64	23	19.1	1.21	0.76–1.81	14	13.2	1.07	0.58–1.79	96	75.6	1.27	1.03–1.55
Leukemia and aleukemia (204–208)	35	36.2	0.97	0.67–1.34	35	39.7	0.88	0.61–1.23	18	25.5	0.71	0.42–1.12	154	156.6	0.98	0.83–1.15
Chronic lymphocytic leukemia (204.1)	8	7.5	1.07	0.46–2.10	8	8.6	0.93	0.40–1.83	4	5.3	0.76	0.21–1.95	34	31.9	1.07	0.74–1.49
Leukemia other than CLL	27	28.7	0.94	0.62–1.37	27	31.1	0.87	0.57–1.26	14	20.2	0.69	0.38–1.16	119	124.7	0.95	0.79–1.14
AIDS (042–044,795.8)	11	32.5	0.34	0.17–0.61	2	8.6	0.23	0.03–0.84	14	30.7	0.46	0.25–0.76	45	146.5	0.31	0.22–0.41
Smoking-related cancers (140-150,157,161–162,188–189)	450	474.5	0.95	0.86–1.04	419	514.8	0.81	0.74–0.90	319	339.8	0.94	0.84–1.05	2,018	1,997.4	1.01	0.97–1.06
Diabetes (250)	91	81.4	1.12	0.90–1.37	80	80.4	1.00	0.79–1.24	54	59.7	0.90	0.68–1.18	341	340.4	1.00	0.90–1.11
Mental and behavioral disorders (290–319)	46	49.6	0.93	0.68–1.24	51	49.6	1.03	0.77–1.35	34	37.5	0.91	0.63–1.27	242	211.9	1.14	1.00–1.30
Diseases of the nervous system (320–389)	91	102.3	0.89	0.72–1.09	104	118.2	0.88	0.72–1.07	72	67.6	1.07	0.83–1.34	414	436.6	0.95	0.86–1.04
Cerebrovascular disease (430–438)	249	265.0	0.94	0.83–1.06	275	305.6	0.90	0.80–1.01	160	175.1	0.91	0.78–1.07	1,033	1,111.1	0.93	0.87–0.99
All heart disease (390-398, 404,410–429)	1,367	1,436.0	0.95	0.90–1.00†	1,532	1,671.5	0.92	0.87–0.96	917	972.3	0.94	0.88–1.01	5,944	6,092.9	0.98	0.95–1.00†
Nonmalignant respiratory disease (460–519)	361	380.4	0.95	0.85–1.05	393	446.6	0.88	0.80–0.97	230	268.1	0.86	0.75–0.98	1,528	1,615.1	0.95	0.90–1.00
Bronchitis, emphysema, asthma (490–493)	143	116.2	1.23	1.04–1.45	133	130.3	1.02	0.86–1.21	94	81.4	1.15	0.93–1.41	543	496.0	1.10	1.01–1.19
Cirrhosis of liver (571)	98	103.6	0.95	0.77–1.15	73	105.7	0.69	0.54–0.87	68	71.3	0.95	0.74–1.21	332	461.5	0.72	0.64–0.80
Nephritis and nephrosis (580–589)	33	34.3	0.96	0.66–1.35	40	35.3	1.13	0.81–1.54	28	25.3	1.11	0.74–1.60	156	137.2	1.14	0.97–1.33
All external causes of death (800–999)	223	263.6	0.85	0.74–0.97	161	229.3	0.70	0.60–0.82	158	188.0	0.84	0.72–0.98	1,041	1,170.4	0.89	0.84–0.95
Accidents (850–949)	123	157.0	0.78	0.65–0.94	101	140.0	0.72	0.59–0.88	89	110.0	0.81	0.65–1.00	636	695.7	0.91	0.85–0.99
Suicides (950–959)	57	66.5	0.86	0.65–1.11	49	64.0	0.77	0.57–1.01	37	46.0	0.81	0.57–1.11	255	306.2	0.83	0.73–0.94
Unknown causes of death	35				35				19				161			

*Exposure combines routine and intermittent.
†Confidence interval does not exclude 1.00.
Obs, observed; Exp, expected; CI, confidence interval; ICD-9, International Classification of Diseases, Ninth Revision; SMR, standardized mortality ratio; CNS, central nervous system; CLL, chronic lymphocytic leukemia.

TABLE 6. Relative Risk of Selected Cancers (ICD-9) by Duration of Exposure to Specific Solvents for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 (Sex and Race Combined)*

Cancer (ICD-9) Years Exposed	Trichloroethylene			Perchloroethylene			Mixed Solvents		
	Obs	RR	95% CI	Obs	RR	95% CI	Obs	RR	95% CI
Esophagus (150)									
0	30	1.00		30	1.00		30	1.00	
<1	7	0.53	0.22–1.24	11	2.30	1.14–4.66	16	1.01	0.55–1.85
1–4	5	0.62	0.23–1.63	7	1.30	0.56–3.02	32	1.16	0.70-1.92
≥5	7	0.77	0.32–1.86	4	0.66	0.22–1.96	52	1.08	0.68–1.74
			$P > 0.20$†			$P > 0.20$			$P > 0.20$
Liver (155, 156)									
0	32	1.00		32	1.00		32	1.00	
<1	10	0.67	0.32–1.42	4	0.71	0.25–2.02	20	1.16	0.66–2.04
1–4	6	0.69	0.28–1.71	6	0.93	0.38–2.27	24	0.79	0.46–1.35
≥5	8	0.83	0.36–1.91	10	1.29	0.60–2.78	43	0.80	0.49–1.30
			$P > 0.20$			$P > 0.20$			$P > 0.20$
Lung (162)									
0	380	1.00		380	1.00		380	1.00	
<1	135	0.98	0.79–1.20	60	1.01	0.77–1.34	185	0.95	0.80–1.14
1–4	76	0.90	0.70–1.16	83	1.25	0.98–1.60	351	1.01	0.87–1.17
≥5	57	0.66	0.49–0.89	52	0.77	0.57–1.04	574	1.03	0.90–1.18
			$P < 0.01$			$P = 0.14$			$P > 0.20$
Breast (174–175)									
0	61	1.00		61	1.00		61	1.00	
<1	6	0.82	0.34–1.98	6	1.40	0.59–3.30	20	0.90	0.54–1.51
1–4	1	0.31	0.04–2.32	1	0.25	0.03–1.81	14	0.68	0.38–1.23
≥5	4	1.47	0.50–4.32	3	1.72	0.53–5.62	35	0.85	0.54–1.33
			$P > 0.20$			$P > 0.20$			$P > 0.20$
Prostate (185)									
0	108	1.00		108	1.00		108	1.00	
<1	42	0.80	0.55–1.16	17	0.87	0.52–1.45	72	1.12	0.83–1.52
1–4	39	1.17	0.80–1.70	28	1.09	0.72–1.66	110	1.02	0.78–1.34
≥5	51	1.21	0.84–1.73	23	0.73	0.46–1.17	222	0.88	0.69–1.11
			$P = 0.13$			$P > 0.20$			$P = 0.07$
Kidney (189.0–189.2)									
0	33	1.00		33	1.00		33	1.00	
<1	6	0.52	0.21–1.30	1	0.18	0.02–1.33	22	1.32	0.76–2.27
1–4	3	0.42	0.13–1.42	5	0.83	0.32–2.16	28	1.01	0.60–1.68
≥5	6	0.85	0.33–2.19	6	0.95	0.38–2.41	33	0.67	0.40–1.11
			$P > 0.20$			$P > 0.20$			$P = 0.03$
Non-Hodgkin lymphoma (200,202)									
0	50	1.00		50	1.00		50	1.00	
<1	18	0.84	0.48–1.47	11	1.26	0.65–2.45	20	0.69	0.41–1.17
1–4	14	1.10	0.59–2.04	10	1.00	0.50–2.00	32	0.73	0.46–1.14
≥5	15	1.02	0.55–1.90	12	1.02	0.53–1.99	83	0.98	0.68–1.42
			$P > 0.20$			$P > 0.20$			$P > 0.20$
Multiple myeloma (203)									
0	29	1.00		29	1.00		29	1.00	
<1	8	0.70	0.31–1.58	4	0.87	0.30–2.51	10	0.61	0.29–1.25
1–4	10	1.45	0.68–3.09	6	1.14	0.46–2.82	23	0.83	0.48–1.44
≥5	5	0.67	0.25–1.83	2	0.34	0.08–1.49	51	0.93	0.58–1.51
			$P > 0.20$			$P = 0.18$			$P > 0.20$

(Continues)

TABLE 6. Relative Risk of Selected Cancers (ICD-9) by Duration of Exposure to Specific Solvents for Lockheed Martin Factory Workers Employed in Aircraft Manufacturing for at Least 1 Year 1960–1996 and Followed Through 2008 (Sex and Race Combined)* *(Continued)*

Cancer (ICD-9) Years Exposed	Trichloroethylene			Perchloroethylene			Mixed Solvents		
	Obs	RR	95% CI	Obs	RR	95% CI	Obs	RR	95% CI
Total cancers (140–208)									
0	1,229	1.00		1,229	1.00		1,229	1.00	
<1	416	0.92	0.82–1.04	198	1.04	0.89–1.21	614	0.96	0.87 –1.05
1–4	282	1.03	0.90–1.18	248	1.15	1.00‡–1.32	1,112	1.04	0.96–1.13
5–9	127	0.96	0.79–1.16	115	0.92	0.76–1.12	603	1.01	0.92–1.12
≥10	146	0.90	0.75–1.07	85	0.83	0.66–1.04	1,256	0.93	0.86–1.01
			$P > 0.20$			$P = 0.10$			$P = 0.06$

*Exposure combines routine and intermittent; exposed workers for whom exposure duration was unknown were excluded from these analyses.
†*P* value for trend (two-sided), calculated by including the midpoint of the exposure category as a continuous variable in the regression model.
‡Confidence interval does not exclude 1.00.
CI, confidence interval; Obs, observed; ICD-9, International Classification of Diseases, Ninth Revision; RR, relative risk.

Consistent with other epidemiologic cohort investigations of workers in the aircraft manufacturing industry,[9–12] several SMRs were statistically significantly below 1.0 in the total cohort. The only SMR that was significantly increased in this study was that for breast cancer (Table 2). The breast cancer SMRs were similarly elevated among factory (SMR = 1.19) and non-factory workers (SMR = 1.11); and these two mortality ratios were not significantly different ($P = 0.53$). The causes of death with the lowest SMRs in the total cohort were AIDS (SMR = 0.28), cirrhosis of the liver (SMR = 0.65), cancer of the cervix (SMR = 0.65), stomach cancer (SMR = 0.73), and external causes of death (SMR = 0.76).

Comparison of the SMRs for factory workers with those for non-factory workers (Table 2), who were classified as having no potential for exposure to chemicals,[2] indicates that the factory workers were more likely to be smokers. Although all were close to or below 1.0, factory workers had significantly higher SMRs ($P < 0.05$) than non-factory workers for lung cancer (SMR = 1.05 in factory workers vs 0.79 in non-factory workers), smoking-related cancers (SMR = 1.03 vs 0.83), heart disease (SMR = 0.98 vs 0.82), and nonmalignant respiratory diseases (SMR = 0.95 vs 0.72). The factory worker SMR was higher than the non-factory worker SMR for each of the individual smoking-related cancers, including buccal cavity and pharynx, esophagus, larynx, bladder and kidney, with the exception of pancreatic cancer (SMR = 1.01 vs 1.02).

Further detailed evaluation of mortality among factory workers showed that the site-specific cancer SMRs were significantly less than 1.0 for buccal cavity and pharynx cancer (SMR = 0.79), stomach cancer (SMR = 0.75), and skin melanoma (SMR = 0.76), and were significantly greater than 1.0 for breast cancer (SMR = 1.19), prostate cancer (SMR = 1.09) and multiple myeloma (SMR = 1.27). Among factory workers, the SMRs did not increase significantly with increasing duration of employment (Table 3) for breast cancer ($P = 0.50$), prostate cancer ($P = 0.67$) or multiple myeloma ($P = 0.99$). Furthermore, there was no evidence that exposure to chromates, TCE, PCE, or mixed solvents increased the risk of breast cancer or prostate cancer (Table 5), even among those with the longest duration of exposure to these agents (Table 6).

Speculation about increased cancer risk among aircraft workers has most often focused on exposure to TCE. The International Agency for Research on Cancer (IARC) concluded that there was limited evidence from human studies that TCE might cause liver cancer and NHL.[13] Virtually every subsequent comprehensive review and meta-analysis of well-conducted occupational cohort studies over the last two decades, with one exception,[14] has generally found no convincing evidence to support a causal association between occupational exposure to TCE and cancer.[15–22] Results suggestive of an association between TCE exposure and cancer have derived almost exclusively from recently conducted community-based case-control studies.[23–25] Employment histories in community studies are self-reported and are quite diverse and heterogeneous in terms of jobs, industry, and geographic location. Exposure assessments in such studies are based on expert opinion and job-exposure matrices, methods that have yet to be validated[24,26]; this lack of validation raises serious questions about the validity and accuracy of findings from these studies, which are increasingly being used to identify and confirm purported occupational causes of cancer.[26,27]

A recent community-based multiple myeloma study[23] using the above-described assessment method reported increased RRs among those exposed to TCE, PCE, and several other solvents. The association was observed in only one of the two study cities, and risk estimates were statistically significant only after a post hoc sensitivity analysis. In a community-based NHL and TCE exposure study,[24] which utilized the same exposure assessment approach and the controls from the multiple myeloma study,[23] increased RRs for NHL were reported among those with the highest levels of TCE exposure, but no dose- or duration-response relationships were observed. The authors, perhaps for the first time, have acknowledged that the occupational exposure assessment methodology used in community-based case-control studies has never been validated.[24]

In contrast, the comprehensive exposure assessment method used in this occupational cohort study, based on review of detailed historical records of job descriptions with job-related chemical usage information, environmental assessment reports, historical industrial hygiene surveys, extensive and multiple group interviews with more than 50 long-term workers, and numerous walk-through visits of aircraft manufacturing facilities, enabled classification of workers according to potential routine (ie, daily) and intermittent exposure to TCE and other specific agents. This approach is not possible in community-based case-control studies, where exposure assessment is hampered by the attendant diversity of self-reported jobs and industries found in any community setting. The inclusion of over 5400 aircraft manufacturing workers in the present cohort with known exposure to TCE allowed for a robust and reliable assessment of the associations of TCE, overall and by duration of exposure, with specific types of cancer.

Factory workers in our study with exposure to TCE, PCE, or mixed solvents had SMRs for multiple myeloma of 1.21, 1.07, and 1.27, respectively, the latter being statistically significant. In

supplementary analyses evaluating only workers with known daily exposure, the most stringent definition of exposure, the corresponding multiple myeloma SMRs decreased to 0.66, 0.92, and 1.06, respectively. Moreover, in internal cohort analyses, RRs for multiple myeloma were below 1.0 among workers with 5 or more years of daily or intermittent exposure to TCE, PCE or mixed solvents (Table 6). Since solvent exposure at the Burbank facilities in the early calendar years was almost exclusively to TCE, most of the long-term workers would have been exposed to TCE.

Furthermore, this study does not provide support for the specific associations suggested by Wartenberg et al[14] between occupational TCE exposure and cancer risk. In particular, the SMRs for factory workers with TCE exposure were 0.92 for cancer overall, 0.89 for liver cancer, and 0.66 for kidney cancer (Table 5), and there was no evidence of increasing risk with increasing duration of TCE exposure for either liver or kidney cancer (Table 6). The SMR for NHL among factory workers with TCE exposure was nonsignificantly elevated (SMR = 1.31), but there was no evidence of increasing risk with increasing duration of exposure to TCE (Table 6). Our findings are consistent with those of other occupational cohort studies of aircraft manufacturing workers, which also found no significant increases of cancer associated with exposure to TCE,[9–12] even among repair and maintenance workers with cumulative TCE exposures likely to be much greater than at Lockheed Martin's Burbank manufacturing facilities. Concerns remain, however, about the possible human carcinogenicity of TCE arising from presumably very high chronic TCE exposures that have occurred in the past in a few occupational settings,[21] but to date there is no convincing evidence from well-conducted cohort studies of workers known to be exposed to TCE that such exposure is associated with cancer risk.[15–20,22]

Perchloroethylene, also known as tetrachloroethylene, has been used as an industrial solvent for more than 60 years. In 1995, the IARC concluded that there is limited evidence in humans for the carcinogenicity of PCE,[13] based primarily on epidemiologic reports of increased risks of cancer of the esophagus, bladder, cervix, and NHL among dry cleaning workers. Among 5830 workers in our study with exposure to PCE, the SMR for NHL was significantly elevated (SMR = 1.43) (Table 5); internal cohort analyses showed nonsignificantly increased RRs for NHL for all categories of PCE exposure duration, but with no significant duration-response trend (Table 6). For virtually all other cancers, the SMRs were close to or below 1.0 among workers with PCE exposure, and no significant trends in RRs according to duration of PCE exposure were observed.

The IARC has classified hexavalent chromium, as encountered historically in chromate production and plating, as carcinogenic to humans.[28] In 2010, the IARC classified employment as a painter to be a cause of cancer in humans, presumably due to chromates found in some paints.[29] Factory workers in our study who had exposure to hexavalent chromium, primarily during metal treating operations (chromic acid mists) or painting with chromate based paint,[2] showed no significant excess of any type of cancer, including cancer of the lung (SMR = 0.95), buccal cavity and pharynx (SMR = 0.67), or larynx (SMR = 0.92) (Table 5). Moreover, no significant excess in mortality from any specific cancer was observed among painters and process operators and platers, specific occupations with the greatest potential for chromate exposure (Table 4). Our results are consistent with results from other cohort studies of aircraft manufacturing workers,[9–12] which also reported no increased risk of lung cancer among those likely exposed to chromate compounds. It is likely that the exposure experience resulting from painting, plating, and processing metals in the aircraft manufacturing industry may be different from that found in other industries in which increased risks of lung cancer have been documented, such as chromate production or plating.[30–33] Although quantitative industrial hygiene data for the current cohort is limited, 37 air samples taken from 1978 to 1988 indicated very little airborne exposure to chromic acid or zinc chromate in the Burbank facilities, with results near the lower limit of detection and well below occupational exposure standards at the time.[2]

To our knowledge, this is the largest epidemiologic cohort study of aircraft manufacturing workers to date, with over 77,000 workers followed for mortality for almost a half century. Limitations of the study include the inability to assign measured quantitative exposure levels for specific agents, as well as the absence of individual information on potential confounding factors such as smoking and alcohol consumption. In addition, numbers of deaths from several types of cancer of a priori interest, including testicular cancer and ovarian cancer, were too small for meaningful evaluation in relation to duration of exposure to TCE, PCE, or chromates.

In summary, this large-scale occupational cohort study with virtually complete follow-up and cause of death ascertainment and comprehensive exposure assessment found no consistent evidence of increased cancer risk overall or for any specific cancer type among aircraft workers, including those employed with direct exposure to TCE, PCE, chromates and mixed solvents over long periods of time.

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